PHYSICAL SCIENCE
LABORATORY MANUAL

PHYS107
(Fall 2011 Version)

A series of experiments designed to introduce students to concepts in physics

Department of Physics & Astronomy
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Introduction

The laboratory portion of this course has several goals:

- This laboratory will provide the student with an opportunity to conduct guided investigations using the scientific method.
- The student will learn to report the results and individual analyses of these experiments in an effective manner.
- The laboratory will emphasize the importance of evaluating the uncertainties that are always present in any experimental investigation via significant figures.

It is much easier to conduct an experiment and quantify the results than to quantify the exact magnitude and sources of the uncertainties in these results. The limitations of the instruments used to make the measurements will be emphasized, starting with the very first laboratory. To help in making more precise measurements, a computer will be utilized in many of the laboratory experiments.

The iMac computer was selected for use in the lab because its use becomes intuitive after only a short time. Some of you perhaps own another type or brand of computer using another operating system. Others of you may have iMac's and are already familiar with the iMac operating system (which is very similar to Windows Vista™ or Windows XP™). Some of you may have never actually used a computer to do more than check your mail. In any case all of you will soon learn how easily some types of physics experiments may be completed using a computer. But one important note must be stressed. In this lab you will be doing the experiment, not the computer. The computer is a tool to use just as you would use a meter stick or digital balance, or even a screwdriver. You must use the tool correctly and you must extract and analyze the results in an appropriate manner.

The computers in this lab are connected to the printer using a wireless network. With a few exceptions, the software applications that you will use are contained in a folder on the desktop. The data that you collect and the reports that you write will be stored on a folder that you will create. Think of your folders as a folder in a filing cabinet. A single folder may contain other folders as well as individual files or papers.

The contents of this laboratory manual are divided into two parts. Part one contains the guides for performing a number of specific experiments. In some of these the use of a computer can prove especially helpful. But, it is emphasized that you should rely on your intuition and knowledge to interpret the information that the computer gives you.

The second part of the manual consists of an appendix of lessons on operating the iMac and associated applications. It also contains textual information relative to laboratory procedures and equipment. Understanding this material is at least as important, if not more so, than understanding the experiments. You will best prepare yourself for lab by studying the appendix items.

You will be required to make measurements and enter these measurements as raw data into applications at various times. As such, the outcome of your experiment (i.e., the conclusions you draw) depends to a certain extent upon your carefulness in making these measurements. At the same time it means that you don't rely upon others to provide you with this type of information. Using someone else's data or results in your experiment or duplicating the answers to questions and conclusions is not acceptable and will result in a grade of zero for both laboratory reports.

Experiment 1
MEASUREMENT

EQUIPMENT

- *3 discs of different diameters*
- *3 spheres of different diameters*
- *3 unknown masses*
- *1 set of standard masses*
- *1 metric ruler*
- *1 vernier caliper*
- *1 electronic balance*
- *1 reflex strip*

Computer Software:
- *Sphere Volume*
- *Circle Area*
- *Calculator*
- *Percent Error Program*

- *1 250g spring scale*
- *1 stopwatch*
- *1 wristwatch or wall clock*

INTRODUCTION

The purpose of this experiment is to become familiar with methods of measurement and error. In the study of physical objects it is very important to be able to systematically measure the quantities of length, mass, and time. In this experiment you will investigate methods of making these measurements. Then you will use the computer to calculate the area and volume of several objects.

Although you are probably more familiar with measuring things in units of pounds, feet, miles, etc., the international community of scientists have adopted a system using kilograms, meters, and for time, seconds. These units form the basis of the SI (Système International) or the MKS (meter, kilogram, second) measurement system. These are metric units. One advantage of the metric system is that it is based on the decimal system. One tenth of a meter is called a decimeter, one hundredth of a meter is called a centimeter, and one thousandth of a meter is called a millimeter. Similarly, 1000 meters is called a kilometer (about 0.62 miles). You will find more information about the metric system and conversions in the appendix.

Every measurement that you make is a comparison. The characteristic you wish to quantify must be measured in comparison to a standard. The first international standard of length was a bar called *The Standard Meter* kept in the *Bureau of Weights and Measures* in Paris. Historically, the meter was intended to be a convenient fraction (1/10,000,000) of the distance between the North Pole and the equator traveling along a line through Paris. There are copies of this standard meter in the laboratory and you will use these as your first technique for measuring length.

The standard unit for mass is the kilogram. *You will use scales that measure mass in grams.* Mass is a property of an object that is related to the gravitational force acting on it, in other words, its weight. **Mass and weight are not the same, and should not be confused.** Mass can also be considered a measure of an object's inertia or resistance to change in motion. Mass is an important property of an object as it can be used in determining the acceleration and momentum of the object. There is, of course, a standard kilogram mass in the Bureau of Weights and Measures. Copies are available in the laboratory. The standard unit of time is the second, and it was defined as 1/86,400 of a mean solar day. It is a bit difficult to keep a copy of the standard clock around since the standard clock is based on the vibrations of a cesium atom. However, there are electronic stopwatches available for your use in the laboratory.

Measurement of Length

There are a number of different ways to measure length. Some you are familiar with, such as simple estimation, the use of rulers, tape measures, and such. Others you may not be so familiar with, such as the use of micrometers, calipers, and electronic rangers. The method chosen to make a linear measurement depends upon the accuracy desired and the distance involved. You can easily estimate the distance from your seat to the door, say three or four meters, but it would not probably be so easy to estimate the diameter of a coin. In the first instance it would be unnecessary to use a ruler graduated in tenths of a centimeter to find the distance, while in the second case it may be very necessary to use calipers graduated in tenths of a millimeter. In this experiment you will try different techniques on several small objects to discover the relative merits of each.

To measure the length of an object, place the object on the ruler exactly on a millimeter mark. Then determine the length by measuring the difference between the two scale positions. That is, the length of the object is the difference in the right and left scale readings. Note that it may be difficult to accurately place the object on the ruler so that you are measuring the exact length. For this reason it is wise to make several measurements of the length and average the results.

A more precise method of measuring length is achieved by the use of a caliper. The object whose length is to be measured is placed between the two jaws of the caliper and held lightly, but firmly. The caliper you will use is designed to measure tenths or hundredths of a main scale division. In this way measurements can be made to tenths of a millimeter while measurements with your ruler can be accurate only to within an estimated 1/2 millimeter.

Measurement of Mass

Mass is usually measured on some type of scale. This scale may be mechanical or electronic. In either case, the gravitational force on the object causes a displacement of the scale mechanism that is then measured. In this laboratory you will use a simple spring scale, then a triple beam balance then a digital balance to find the masses of some objects.

To use the spring scale, simply attach the object whose mass is to be measured to the spring hook and read the value adjacent to the scale pointer. This is a fast but not particularly precise method. A better method is measurement by the triple beam balance. Here the mass to be measured is placed on the weight pan and the sliding masses on the balance beams are adjusted to give a zero reading at the pointer. The mass of the object is then read as the sum of the values at which the sliding masses are aligned. The most accurate method we will use is the electronic balance. Simply place the object on the pan and read the measurement.

Measurement of Time

Time is the easiest physical quantity to measure. Most everyone wears a wristwatch these days, and some hand calculators have a clock function. In laboratory exercises you may sometimes keep track of time with wristwatches or wall clocks. However, for more accurate measurements you will use a stopwatch. This timepiece measures time to a hundredth of a second and will serve as the time standard in this experiment.

Calculation of Area

It is quite often necessary to calculate the area of an object. To help you make such mathematical calculations you are going to use a computer program.

Remember that *the area of a rectangular surface is equal to its length times its width,* so that the surface area of an object 1-cm high and 1 cm wide is 1 cm^2 (one square centimeter). An object 2-cm high and 4 cm wide would have an area of 8 cm^2 (eight square centimeters).

The area of a circle is equal to pi (π) times the radius of the circle squared (πr^2). Since the radius is one half the diameter, you can remember that the area of a circle is equal to pi times one half the diameter squared. In one part of the experiment you will calculate the surface areas of several discs whose diameters you have measured.

Calculation of Volume

Sometimes it is necessary to calculate the volume of an object. For instance, *the volume of a rectangular object is equal to its length times its width times its height or L*W*H.* For example, an object 2m high, 3m wide, and 4m deep has a volume of 24m^3 (24 cubic meters).

The objects that we will measure in this lab are more common than cubes and rectangles. They are spheres. Thus it is necessary to know how to calculate the volume of a sphere. The formula is:

$$Volume = \left(\frac{4}{3}\right)\pi R^3$$

or using R = D/2

$$\text{Volume} = \left(\frac{1}{6}\right)\pi D^3$$

where D is the diameter of the sphere.

Use the computer and the appropriate program to make this calculation. By using the correct program, it is only necessary to enter the diameter of the object that you have measured. From this, the volume of the object will be determined. In this way, you are able to complete the same calculations for various objects very quickly. This illustrates that computers are very useful in doing repetitive computations.

Calculation of Error

It is important to recognize that any measurement you make is subject to error regardless of the care with which you make the measurement. To indicate how precise or reliable a given measurement is, it is often convenient to determine the percentage error. The percent error can be calculated using the following formula:

$$\%\ \text{error} = \left|\frac{T - M}{T}\right| * 100$$

Where T is the true value and M is the measured value.

Whenever the true value of the quantity is known, you can calculate percent error and determine the accuracy of your experiments. In some experiments this will be possible, in others it will not. But, whenever you are given the correct value for a quantity, you should calculate the percent error of your measurement. The sign of the percent error is not significant. Record the absolute value (% error without a sign) on your data sheet. Make certain you understand the number of significant figures to report. See Appendix F.

PROCEDURE

Discs & spheres are in plastic bag.

A. Measurement of Length

1. Make a best guess estimate of the diameters of 3 different discs. Your answer should be in metric units. Since you may not be familiar with metric sizes, you may use a metric ruler for reference, but do not place the ruler on the object yet. Record your best guess to the 1/2 cm in the space provided in the data table.
2. Now use the ruler to measure the diameters of the 3 disks. The ruler can measure length to 1 mm (0.1 cm). Record the measurements on the data chart.
3. Repeat the measurements using a caliper. The caliper can measure lengths to a resolution of 0.01 mm or 0.001cm. Record the results.
4. Use the ERROR program to calculate the percent error of your estimates and the measurements made with the ruler. **Use the caliper measurements as the true values.** Record your findings on the data table.
5. Measure the diameters of 3 different spheres by repeating steps 1 through 4. Record the results on the data table.

B. Measurement of Mass

6. Obtain 3 objects of unknown mass from your laboratory instructor. Estimate the mass of each of these objects by holding the object in one hand and some known mass, from the standard mass set, in the other hand. Record your estimates.
7. Now measure the unknown masses using the spring scale. Record the results.
8. Repeat the measurements with the triple beam balance and record the results. Note the 100g and 500g scales have notches for the sliding masses. The sliding masses must be in a notch to get a correct reading.
9. Repeat using the electronic balance.
10. Use the ERROR program to calculate the percent error of your estimate, the spring measurement, and triple beam balance measurement. Use the electronic balance as the true value. Record the results.

C. Measurement of Time

11. Estimate a 30-second interval by counting (you can tap your foot or use your heartbeat to establish rhythm). Your lab partner should time you in this exercise with the stopwatch. Help your partner by giving him or her start and stop commands. Record your estimates.
12. Measure a 30-second interval by watching the wall clock or the second hand on your wristwatch. Again give your partner start and stop commands so they can time you with the stopwatch. Record the results.
13. Use the reflex testing strip to find your time to start and stop the stopwatch. Do you think you can actually measure time to $\frac{1}{100}$ second (0.01 sec.) using this watch? (See Question # 7)

14. Use the %ERROR program to calculate the error of your estimates and clock watching. **Remember that the stopwatch is your true value.** Record the results.

D. Calculation of Area and Volume

15. Run the CIRCLE AREA and SPHERE VOLUME programs to find the area of each disk and the volume of each sphere. Record the results.

Experiment **1** *DATA SHEET*

Name: ______________________________ Section: __________

A. Measurement of Length

Object	Estimated Diameter (cm)	Diameter by Ruler (cm)	Diameter by Caliper (cm) (TRUE)	% Error of Estimate	% Error of Ruler Measurement
disc 1					
disc 2					
disc 3					
sphere 1					
sphere 2					
sphere 3					

B. Measurement of Mass

Object	Estimated Mass (g)	Mass by Spring Scale (g)	Mass by Triple Beam Balance(g)	Mass by Electronic Balance (g) [True]	% Error of Estimate	% Error of Spring Scale Measurement	% Error of Triple Beam
unknown 1							
unknown 2							
unknown 3							

C. Measurement of Time

Estimate of Time	Stopwatch Time (s) [TRUE]	Time Measured On Clock (s)	Stopwatch Time (s) [True]	% Error of Estimated Time	% Error of Watched Time	Reflex Time (s)
30 sec		30 sec				

Experiment 1
DATA SHEET

D. Calculation of Area and Volume

Object	Calculated Area (cm^2)
disc 1	
disc 2	
disc 3	

Object	Calculated Volume (cm^3)
sphere 1	
sphere 2	
sphere 3	

QUESTIONS

1. What was the purpose of this experiment?

2. What is the standard unit for length, mass and time in the MKS metric system?

3. Why are units important when reporting the result of a measurement?

4. An object is estimated to be 2.5 cm long. When measured with a Vernier caliper its true length is determined to be 2.47 cm. What is the percent error of the estimated value?

5. Complete the following calculations using the explanation of significant figures given below.

- When **multiplying and dividing** several quantities, the number of significant figures in the final answer is the same as the number of significant figures in the quantity with the least amount of significant figures that is being multiplied.
- When **adding and subtracting** several quantities, the number of decimal places in the result should equal the smallest number of decimal places of any term in the sum.

Given: $x = 12.24$ $y = 5400$ $z = 11.572$

Determine: $x * y * z =$ ________

$x + z =$ ________

6. Consider the results of your reflex time measurement. What precision, in fractions of seconds, can you claim for the stopwatch?

Experiment 2
MOTION: Distance Graphs

EQUIPMENT

Motion detector	*Lab Pro Interface*
Notebook	*Power supply*
Motion program	*USB cord*

Name: ______________________

Section: ____________________

INTRODUCTION

In this investigation, you will use a motion detector to measure how you move. As you walk (or skip, or jump, or run) the graph on the computer screen displays how far away from the detector you are at a given time.

Your primary task in this experiment is to *generate and interpret* two types of plots- **Distance vs. time** plots and **Velocity vs. Time** plots. Understanding the fundamental physics involves understanding the shape of these plots when motion occurs at a constant speed (i.e., motion with zero acceleration) and at a non-constant speed (i.e., accelerated motion). You should note that there are *two types of acceleration*-constant (e.g., acceleration of gravity) and non-constant (e.g., normal accelerating or braking in a car).

For Distance vs. time plots the primary behavior that you should know is that for objects traveling at constant speeds the plot is a **straight line** with a slope that represents the speed- *The greater the speed, the greater the slope, and vice versa*. For objects that accelerate, the distance vs. time yields **some type of curve** (e.g., a parabola in the case of constant acceleration).

Velocity vs. time plots are derived from distance vs. time plots and are constructed by picking a particular time (on the distance vs. time plots), finding the slope at that time (i.e., the speed at that time) and plotting these points.

For objects traveling at constant speeds these plots have a constant slope and plot as a horizontal line. For objects traveling at a constant acceleration the slope at a particular time (i.e., the velocity) changes at a constant rate and as a consequence velocity vs. time plots as a *straight line* with a non-zero slope.

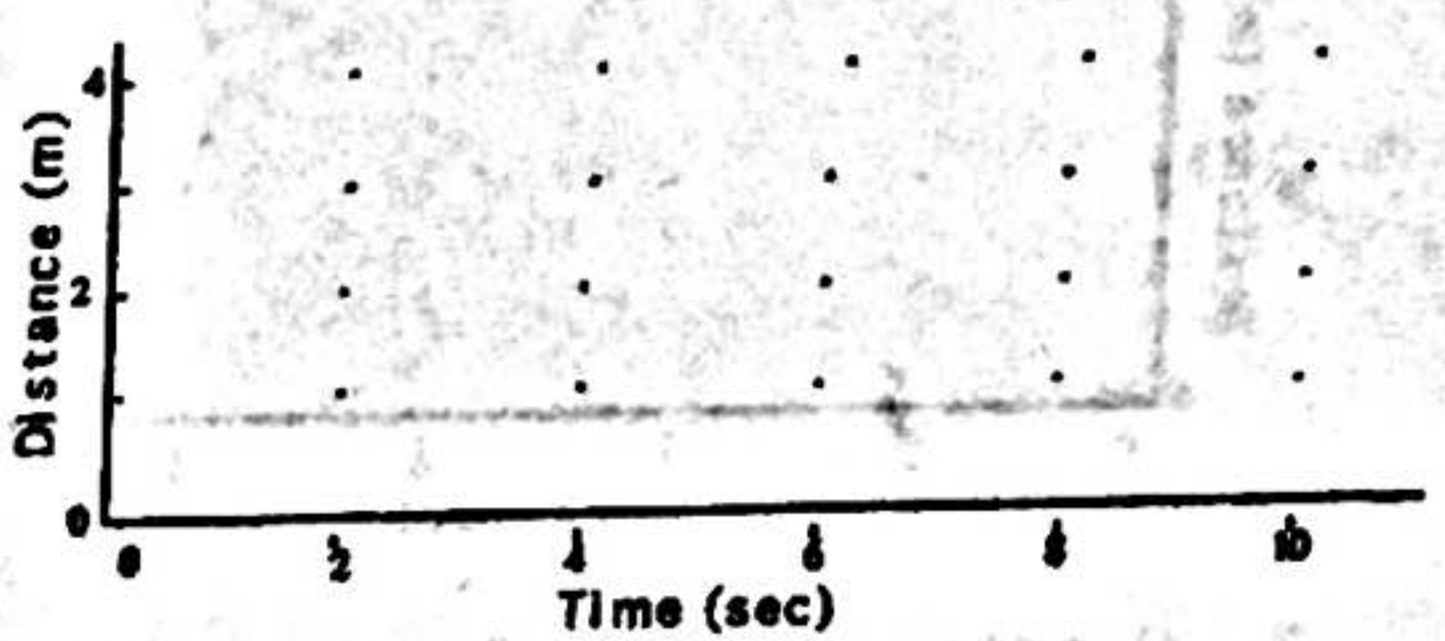
We will make distance/time graphs for different walking speeds and directions. Place the motion detector on top of two stacked stools. Hold a notebook or piece of paper at the horizontal level of the motion detector as you move. This provides a more uniform reflection surface.

PROCEDURE

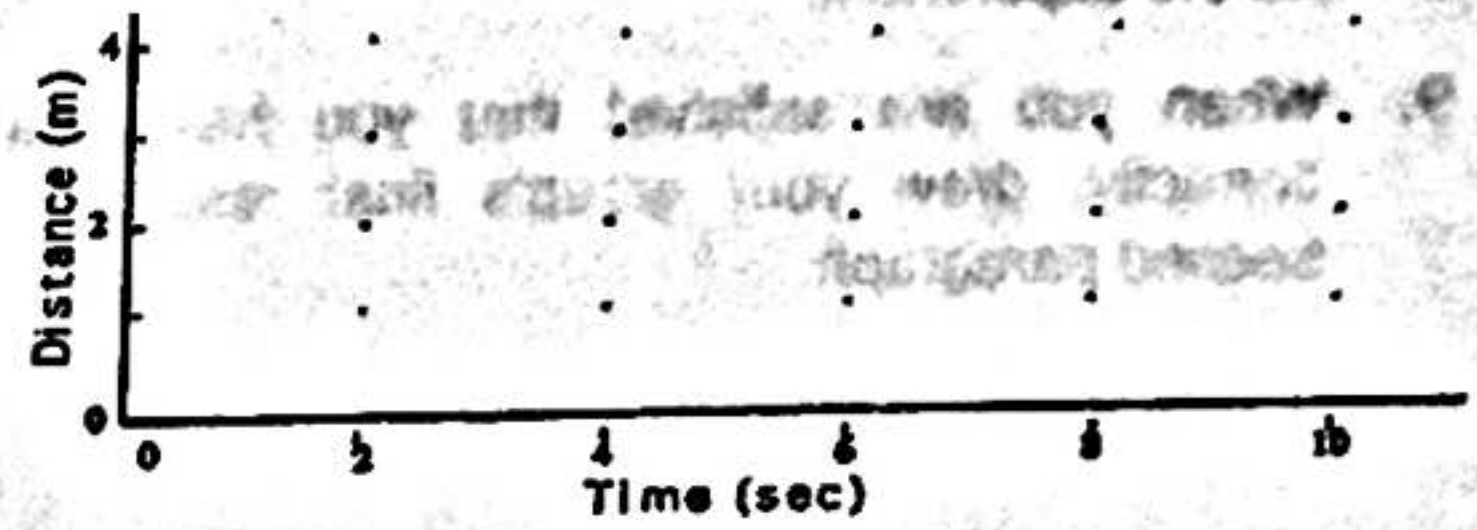
A. Making Distance Graphs

1. Select the MOTION experiment. The Logger Pro application should open.

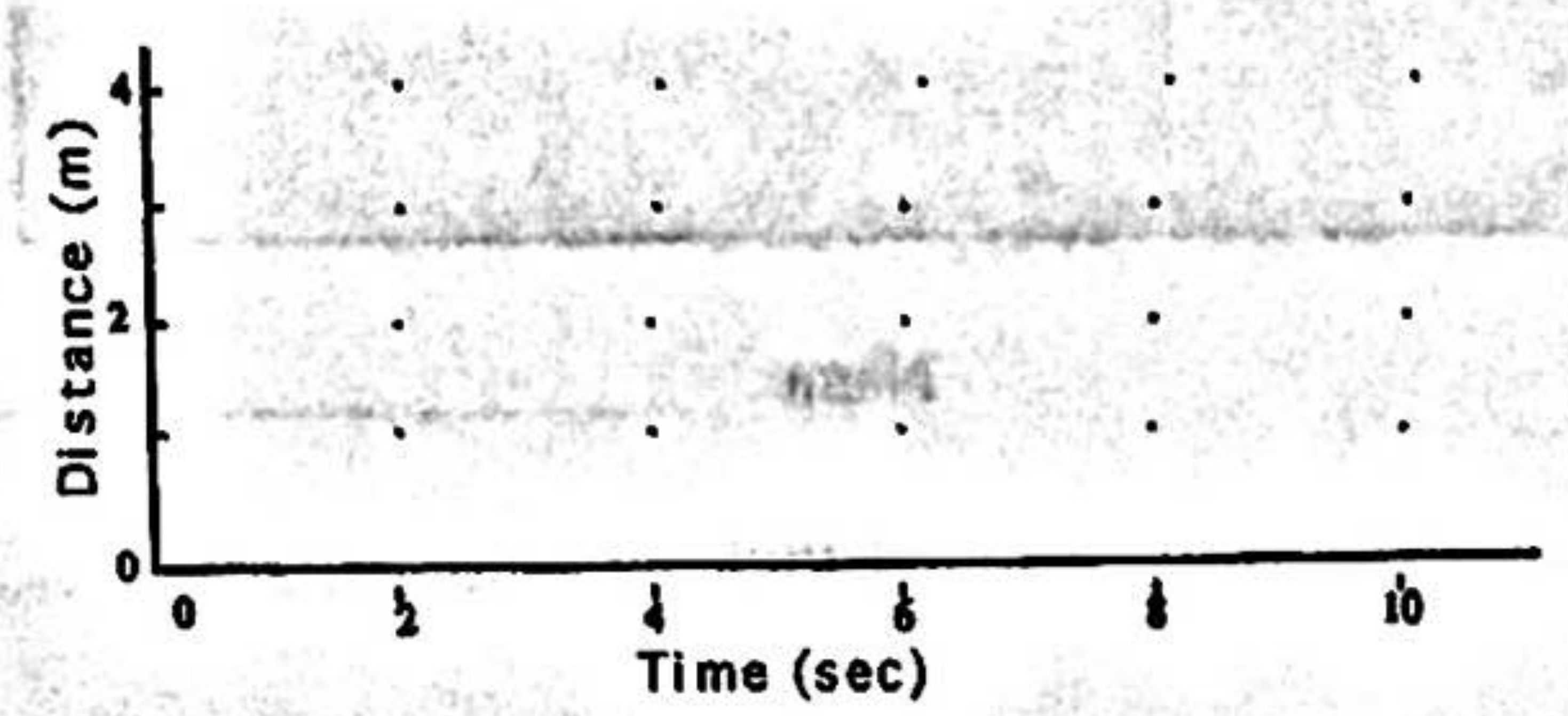
2. Start at the 1/2-meter mark and make a distance/time graph by clicking COLLECT and walking *slowly away* from the detector. Sketch the graph below. Be sure to note the values on the axes.



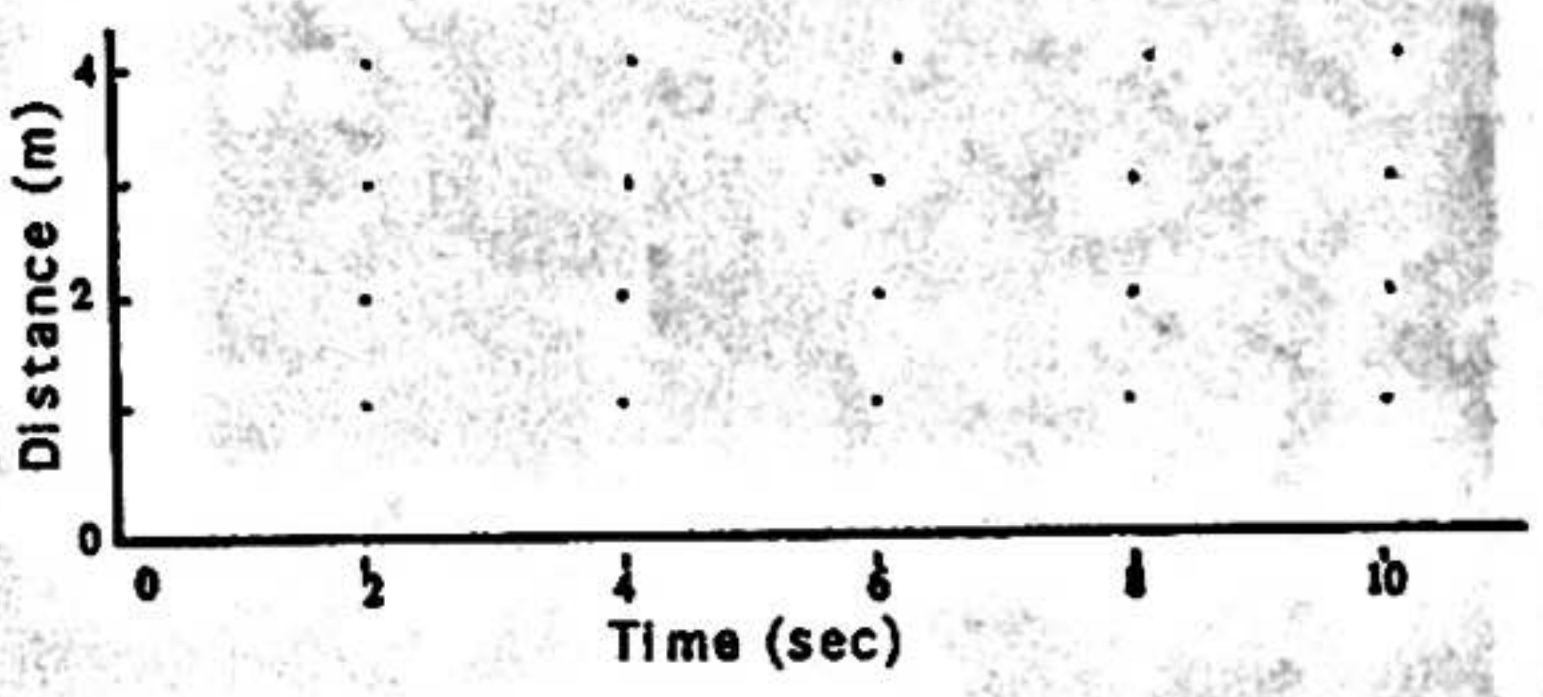
3. Make a distance/time graph walking *slowly towards* the detector. Sketch the graph.



4. Make a distance/time graph walking medium fast toward the detector. Sketch the graph.



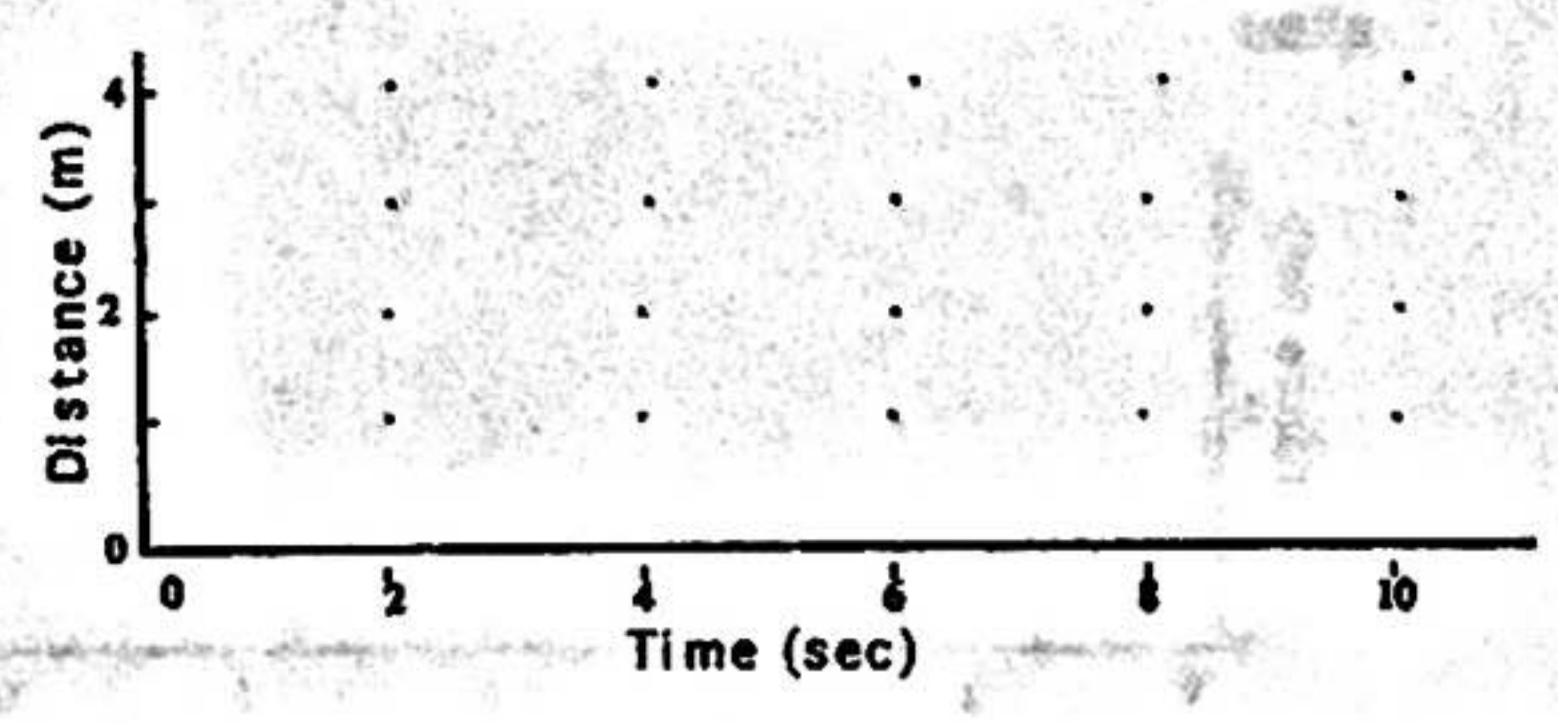
5. Make a distance/time graph, walking *medium fast* away from the detector. Sketch the graph below. You may run out of walking room before the 10 seconds runs out. Just draw the graph that reflects you walking away.



B. Predicting a Distance Graph

6. Each person draw below, using a dotted line, your prediction of the graph if a person starts at the 1-meter mark, walks steadily and slowly away, stops for 4 seconds, and then walks quickly back.

PREDICTION

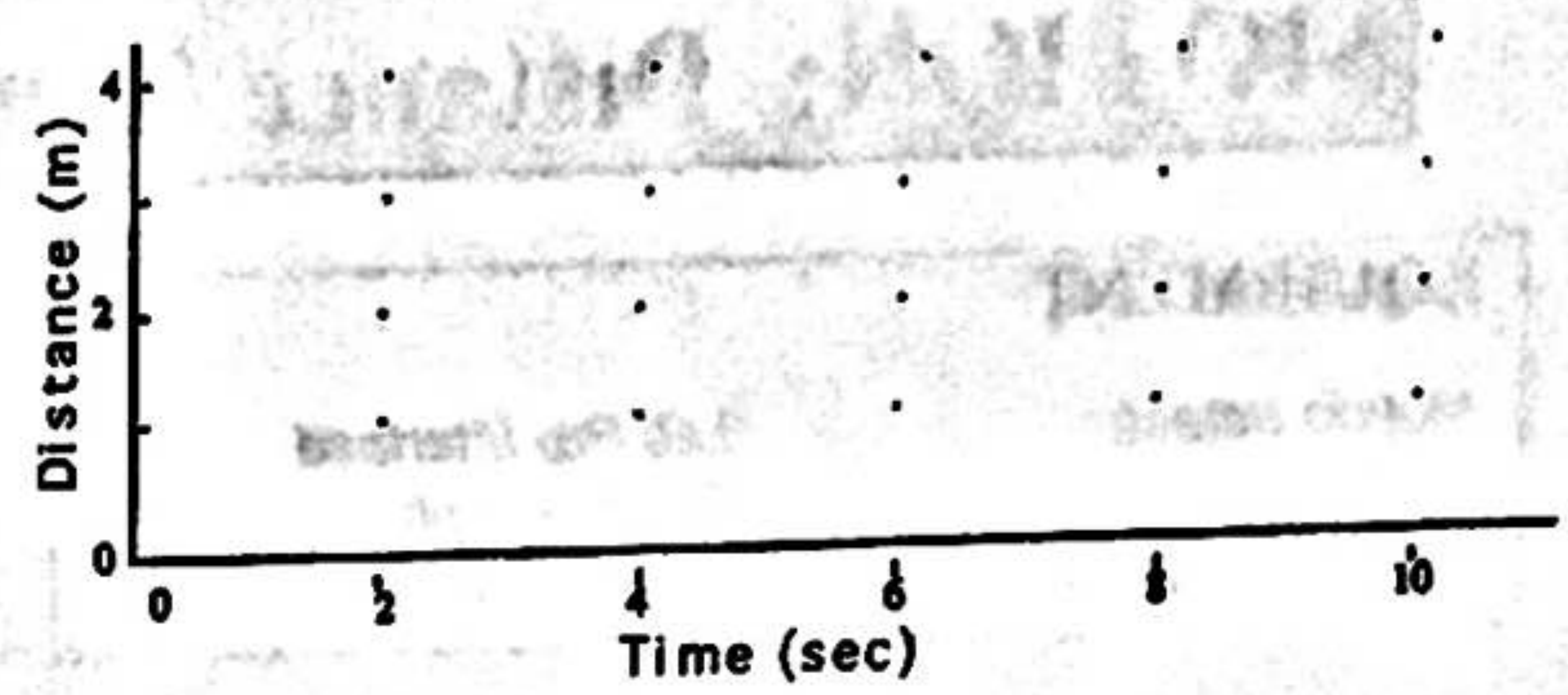


7. Compare predictions. See if you can all agree. Using the above graph draw with a solid line of the prediction your group agrees on.

8. Do the experiment.

9. When you are satisfied that you have walked correctly, draw your group's final result on the second paragraph.

FINAL RESULT

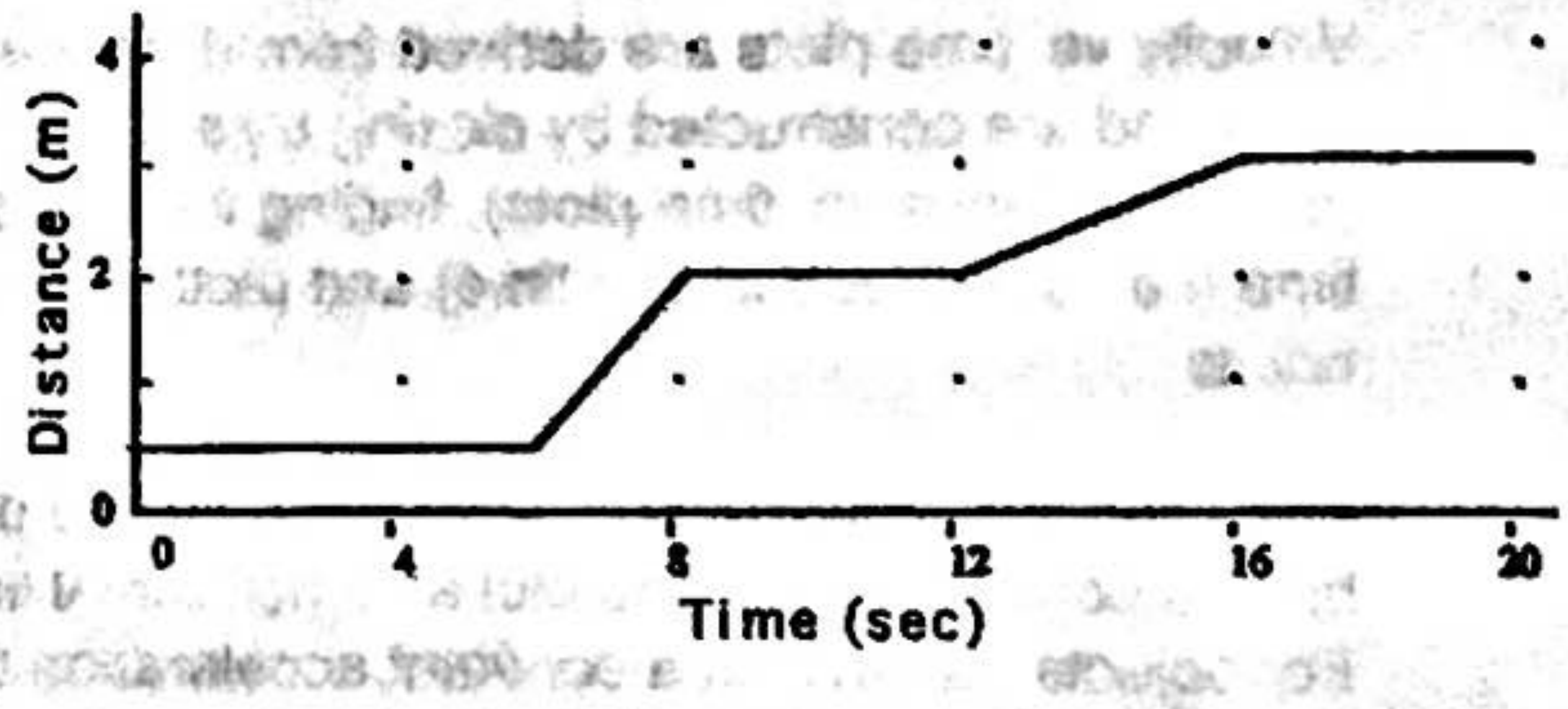


10. Is your prediction the same as the final result? If not, describe how you would move to make a graph that looks like your prediction.

C. Match this Graph

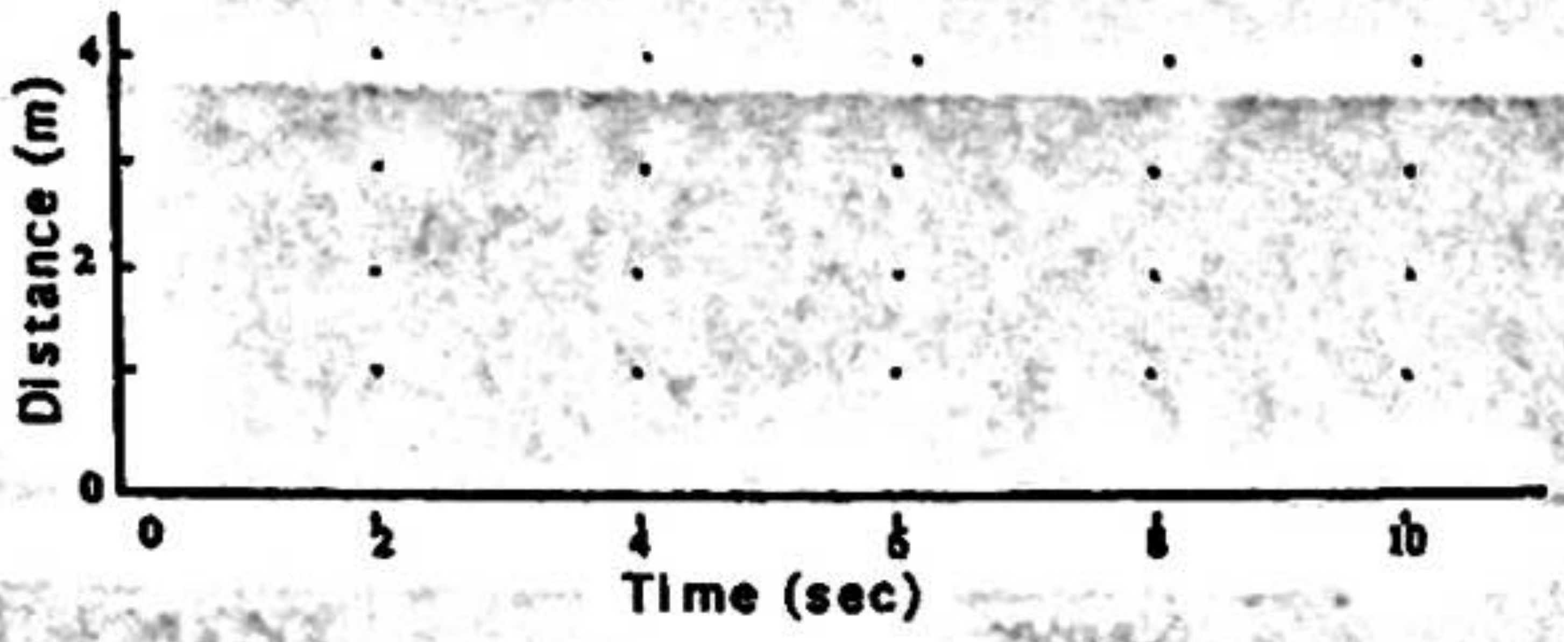
11. You will need to change the timescale to 20s. To change the timescale, click the last number on the horizontal scale and type 20 in its place.

12. Move so the computer displays this graph. You may try a number of times. Each person should take a turn.



D. Challenges

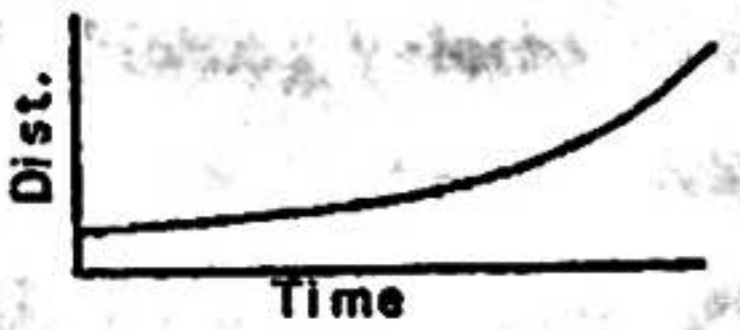
13. If necessary, change the experiment length back to 10s. Make up your own distance graph. Turn the screen, if necessary, so that the walking person can see the screen. Use straight lines, no squiggles. Then see how well people in your group can duplicate on the screen the graph you draw.



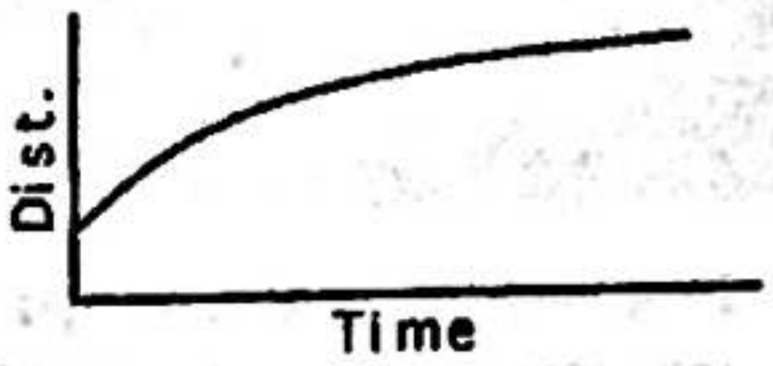
14. **Can you make a graph with curved lines?**

Try to duplicate the shapes below.

Graph A



Graph B



Graph A:
Did you succeed? ________
How? ____
____

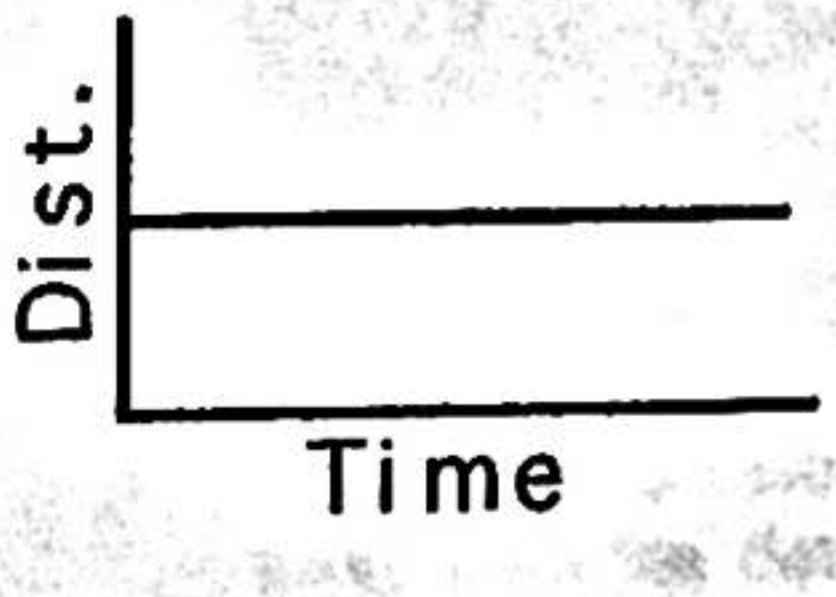
Graph B:
Did you succeed? ________
How? ____
____

15. Close "Distance Graph"

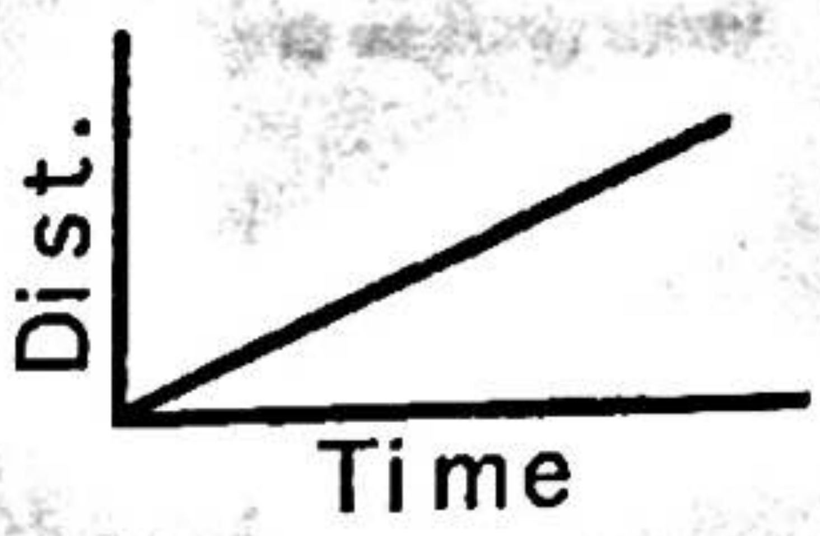
Experiment 2
Distance: DATA SHEET

Name: ____________________

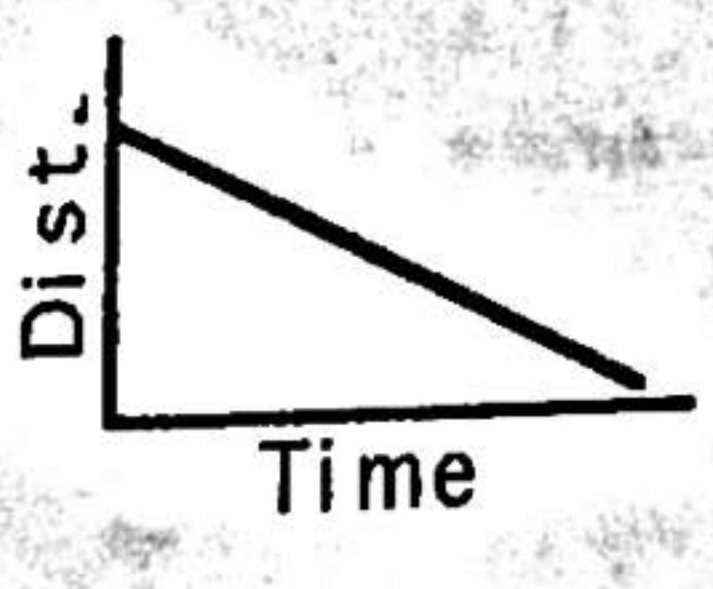
Section: ____________________



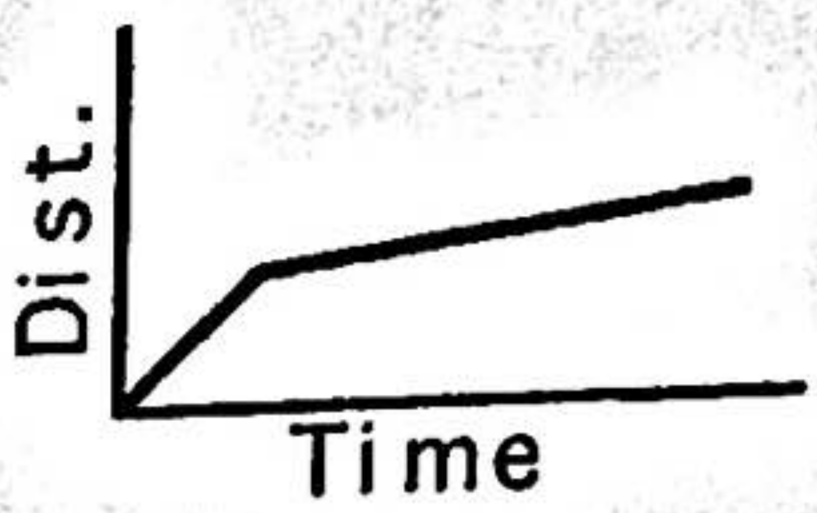
1. What do you do to create a horizontal line on a distance/time graph?



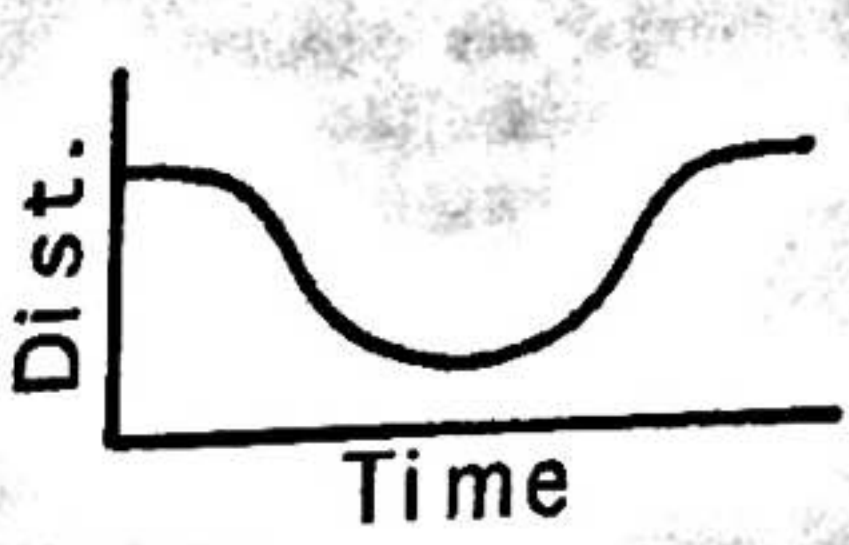
2. How do you walk to create a straight line that slopes up?



3. How do you walk to create a straight line that slopes down?



4. How do you move so the graph goes up steeply at first, and then continues up gradually?



5. How do you walk to create a U-shaped graph?

Experiment 2

MOTION: Velocity Graphs

EQUIPMENT

Motion Detector
Notebook

Name: ______________________

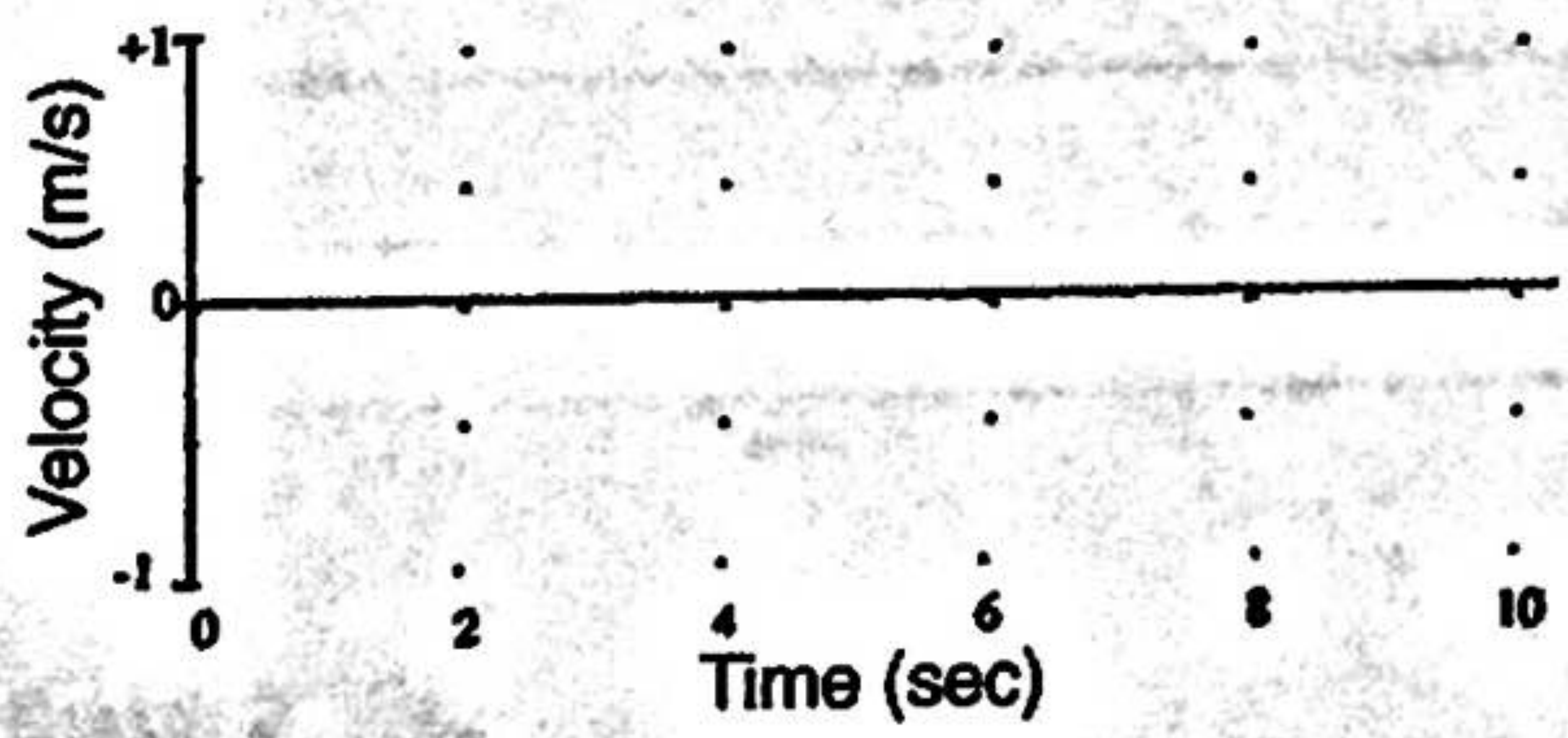
Section: ______________________

PROCEDURE

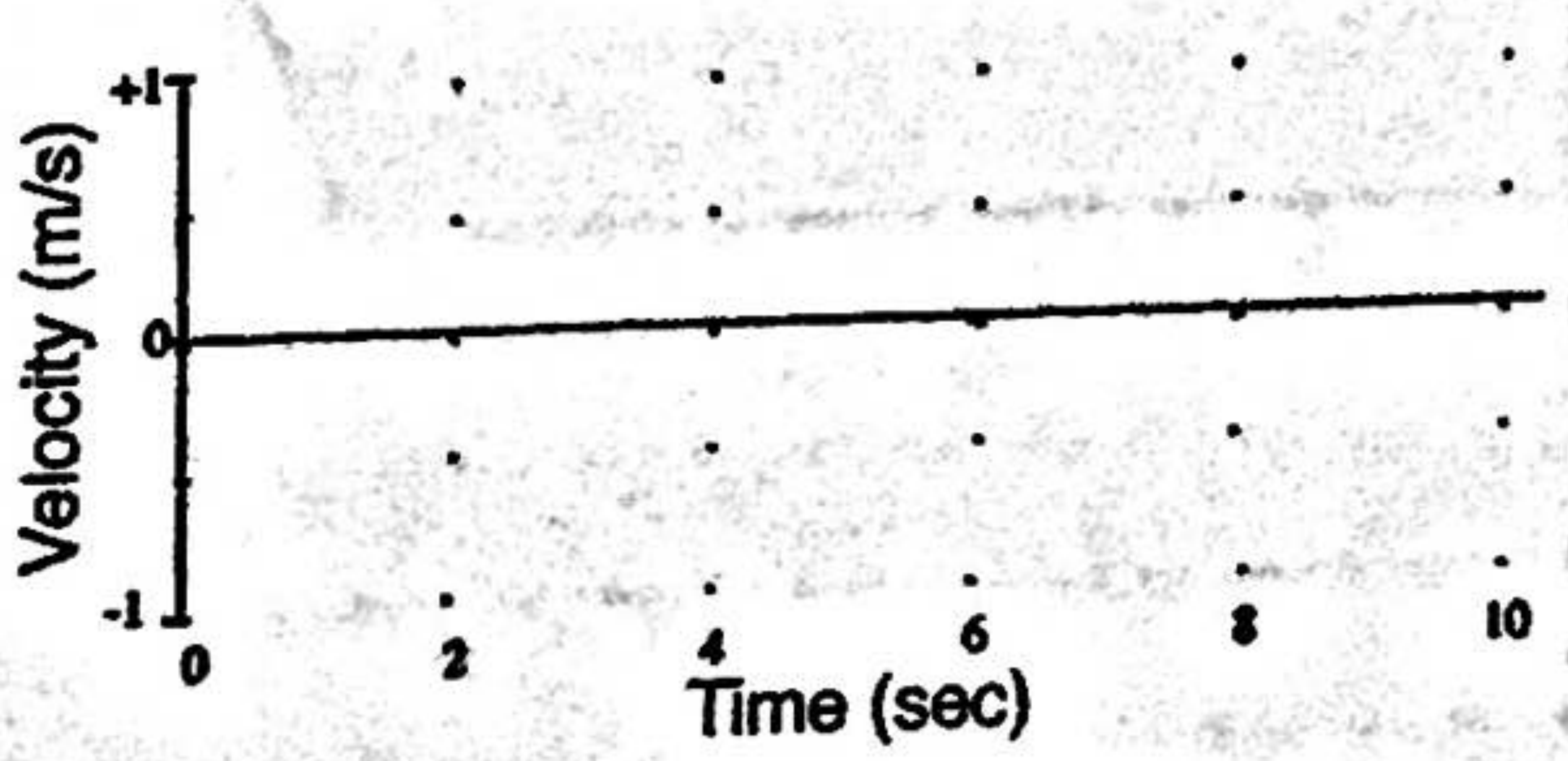
E. Making Velocity Graphs

16. Open file named "Velocity Graphs".

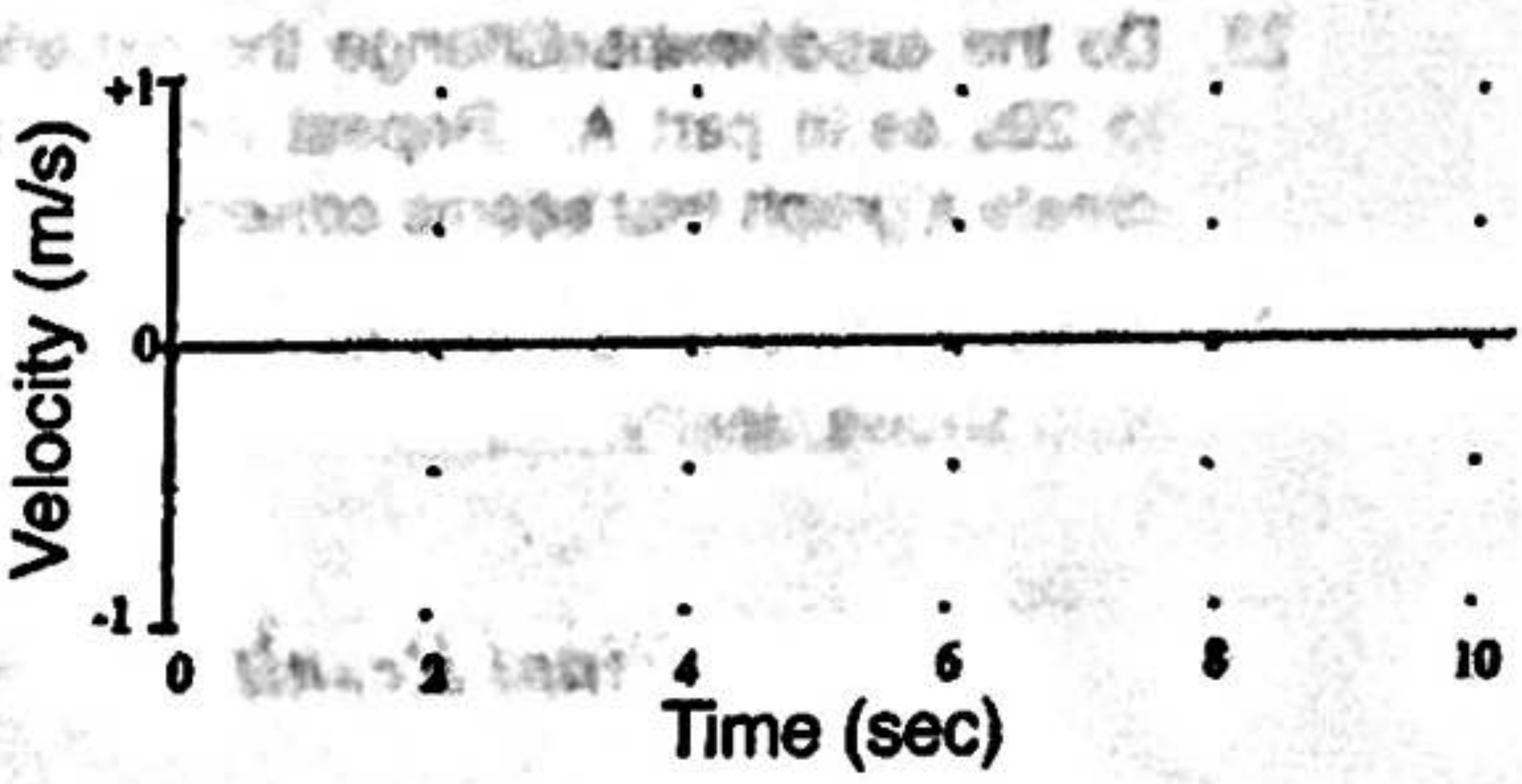
17. Make a velocity graph by *walking slowly* and *steadily* away from the detector. Try again until you get a graph you're satisfied with. Sketch the result here. (Just draw smooth patterns; leave out little wiggles and bumps).



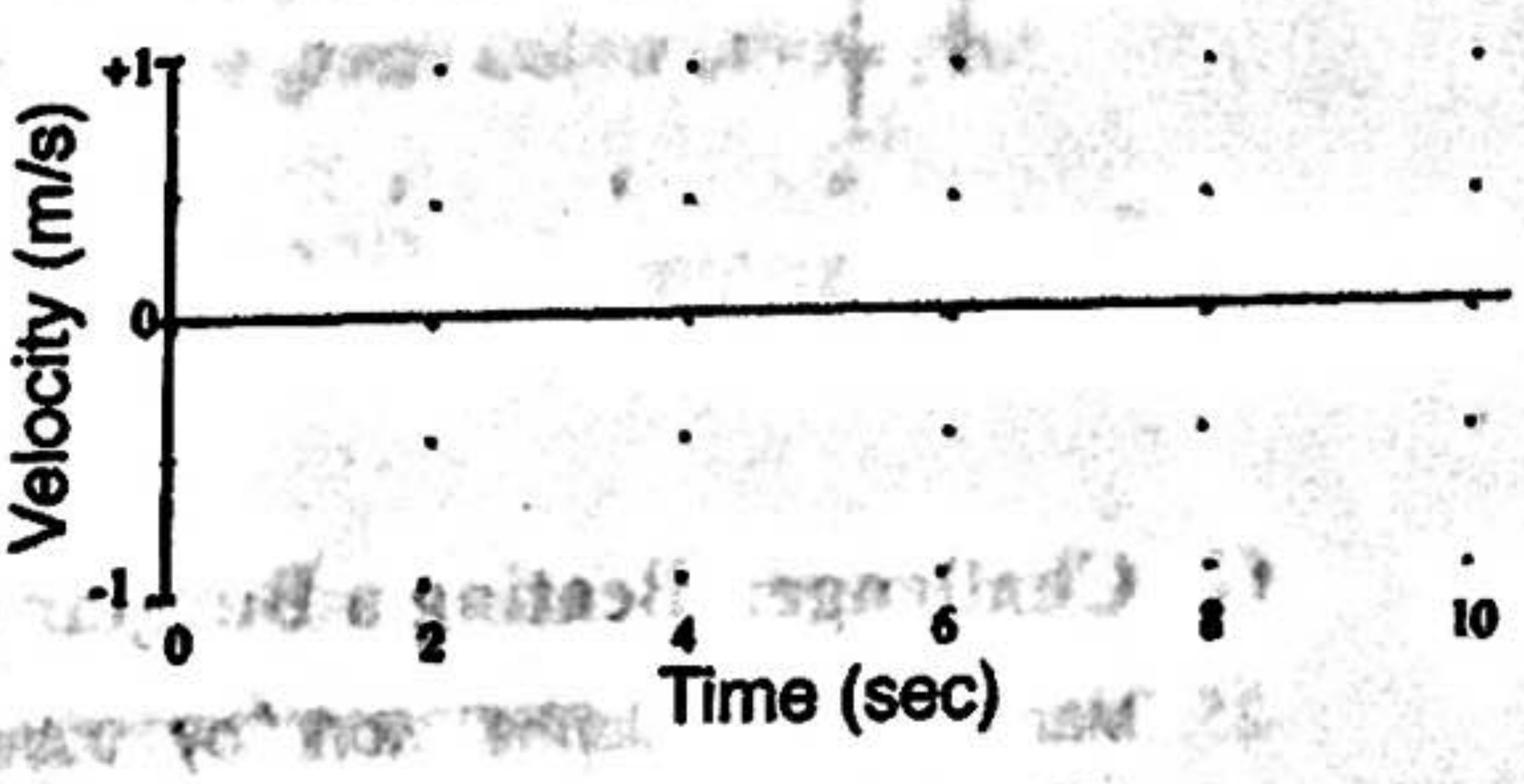
18. Make a velocity graph by walking *medium fast* and steadily away from the detector. Sketch your graph.



19. Make a velocity graph by walking slowly and steadily toward the detector. Sketch your graph.



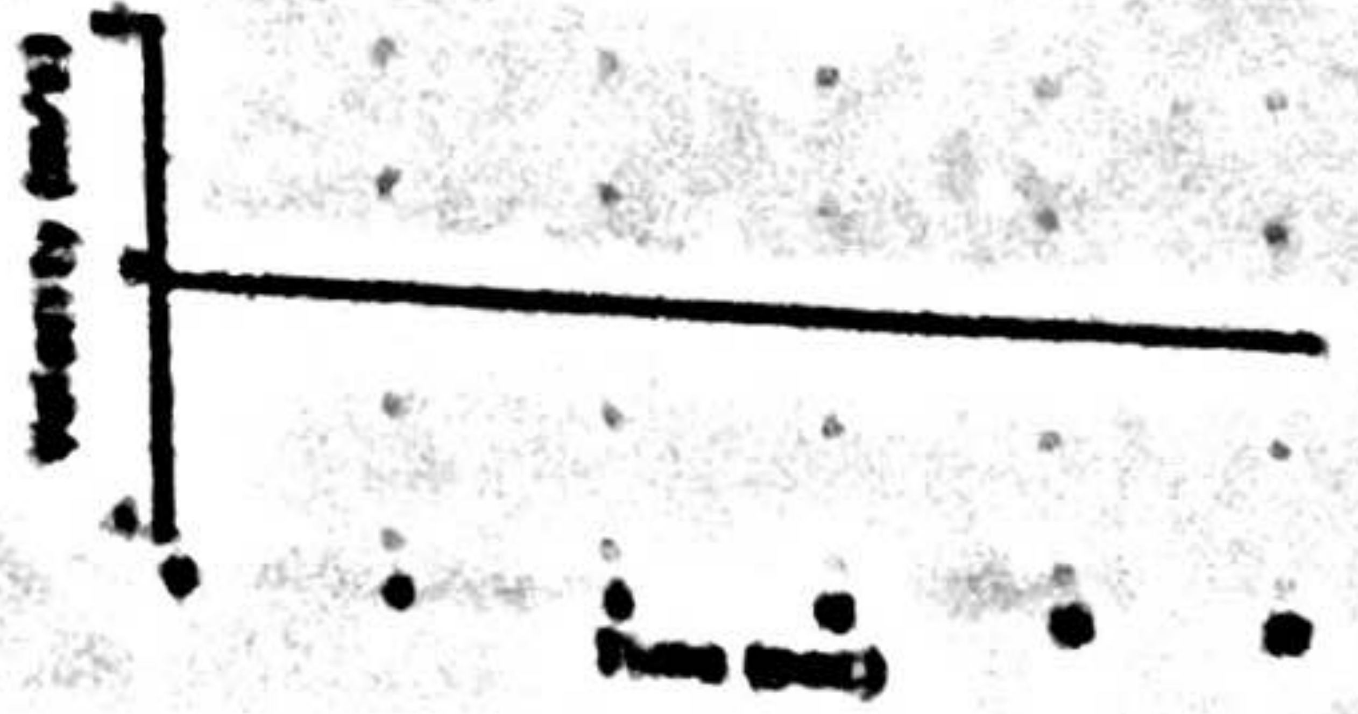
20. Make a velocity graph by walking *medium fast* and steadily toward the detector. Sketch your graph.



F. Predicting Velocity Graphs

21. Each person draw below, using a *dotted line, your prediction of* the velocity graph produced if you walk slowly and steadily away from the detector then stop for 4 seconds, then walk quickly back to the detector.

Prediction

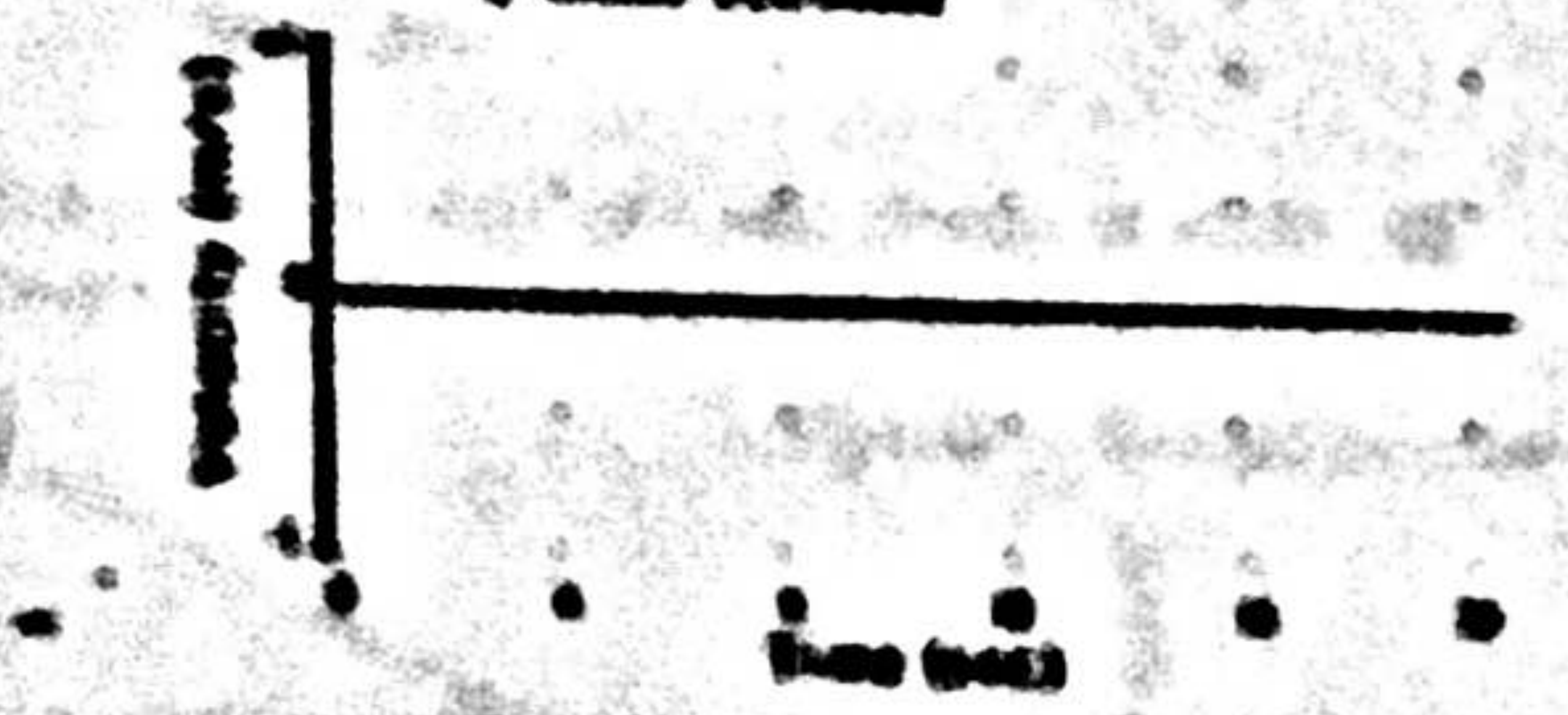


22. Compare predictions and see if you can all agree. Use a solid line to draw in your group prediction using the above graph.

23. Do the experiment. Change the experiment length to 20s as in part A. Repeat experiment until you create a graph that seems correct.

24. Draw the best graph below. Be sure the 4-second stop shows clearly.

Final Result



G. Challenge: Beating a Burglar Alarm

25. Many burglar alarms work by using a motion detector to sense moving objects. Because these motion detectors are not very sensitive, you can fool one by moving very slowly.

26. Each member in the group should find how slowly you have to walk so the velocity graph barely registers your motion.

27. See how far you can move in 20 seconds without triggering the burglar alarm. Use the distance and velocity graphs. If the velocity graph moves more than a very small amount above or below the axis, you have triggered the alarm. Record each partner's best distance.

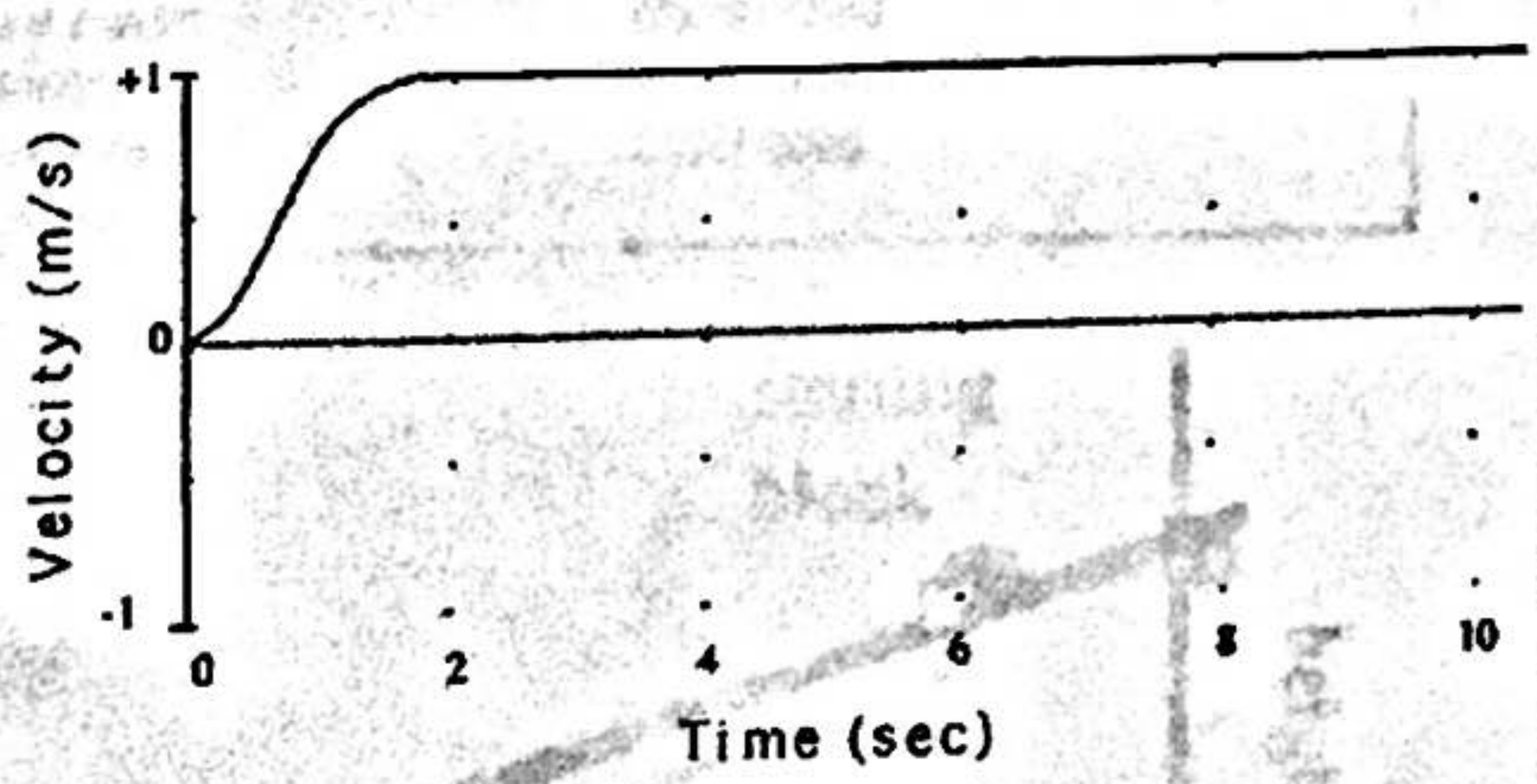
28.

Name	Distance in 20 Seconds

QUESTIONS

1. Describe clearly how to move to make each of the following three graphs. You may want to study the velocity graphs you made today to help you think about this.

Graph 1



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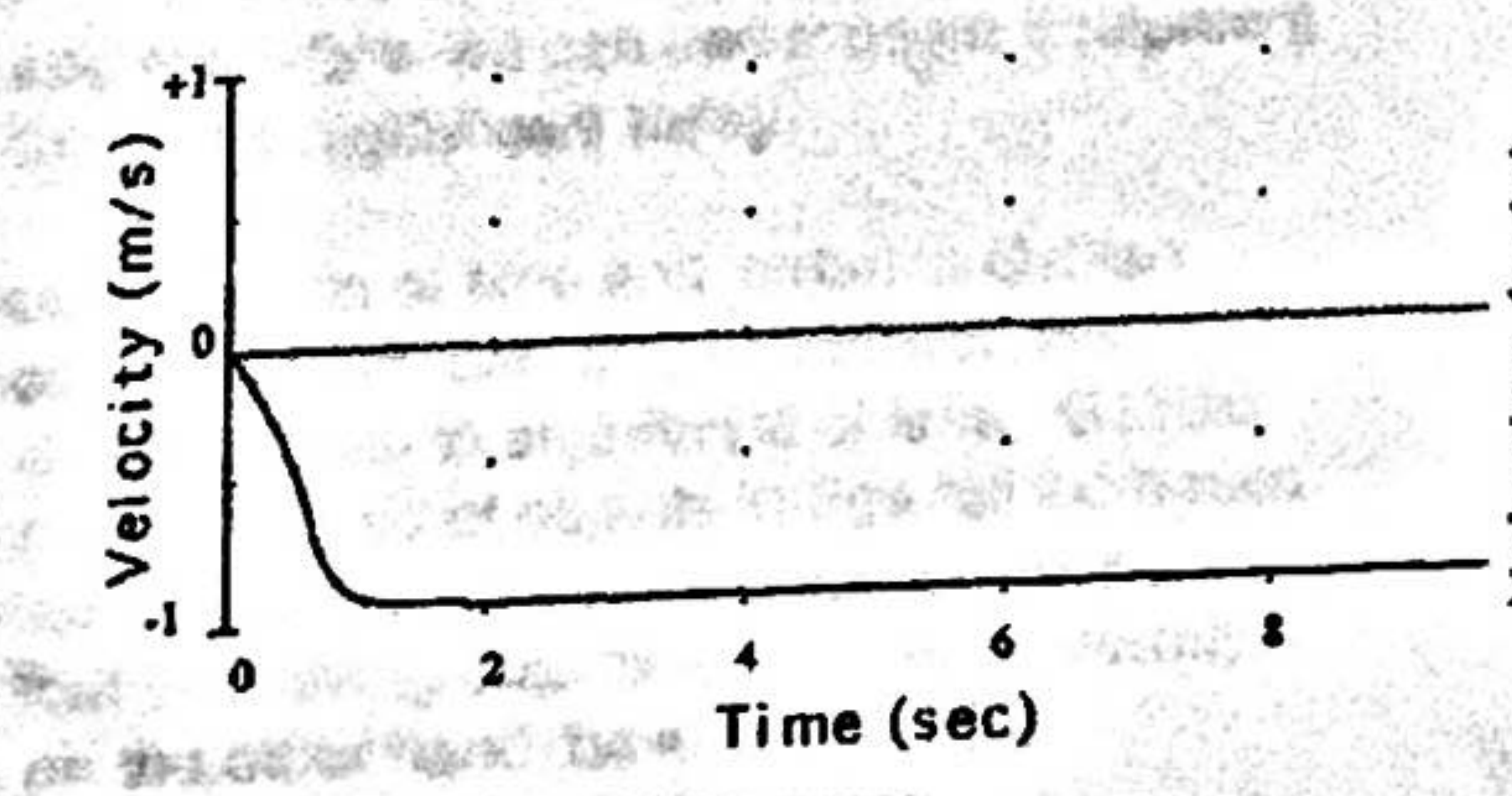
Graph 2



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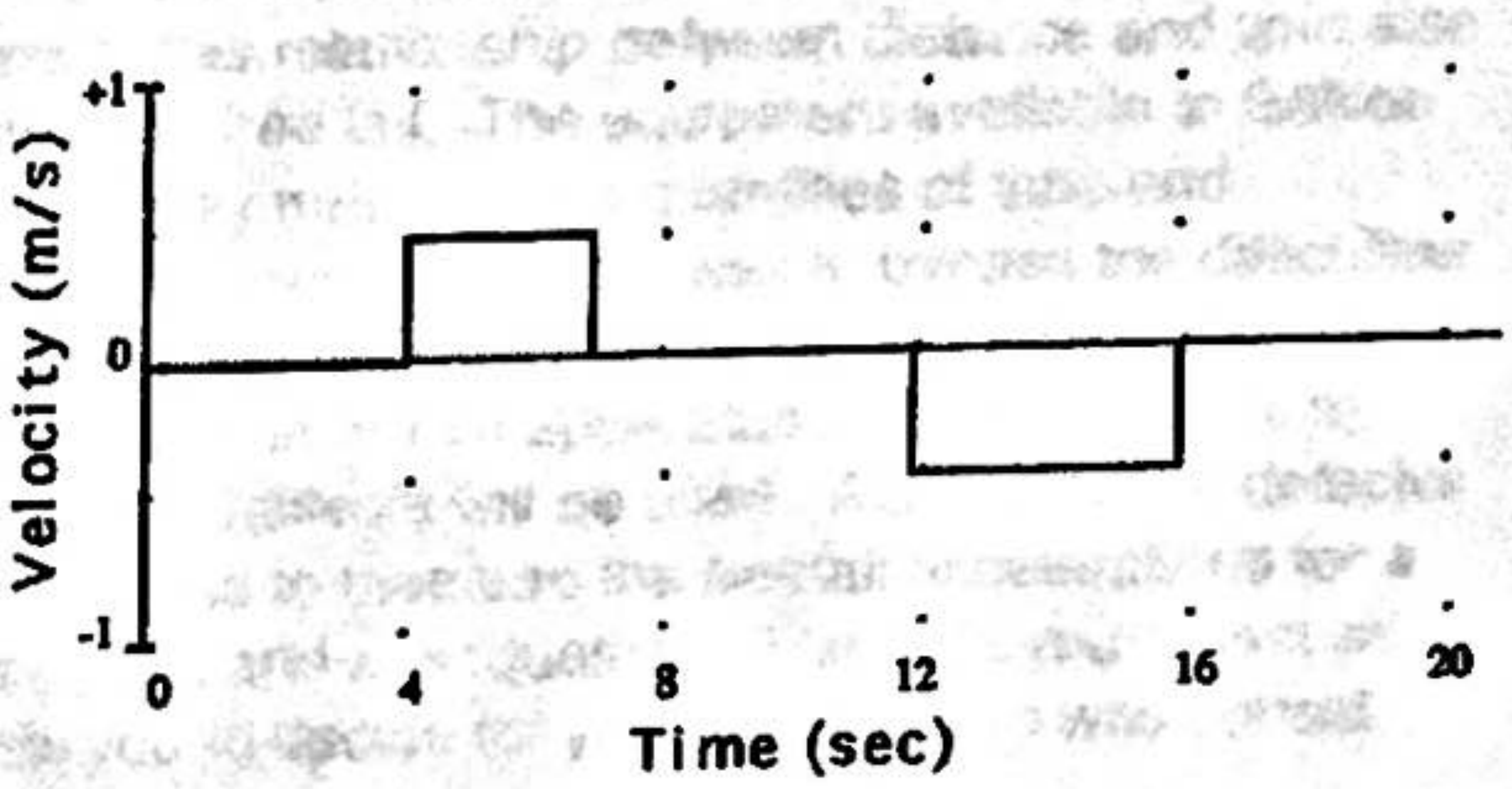
Graph 3



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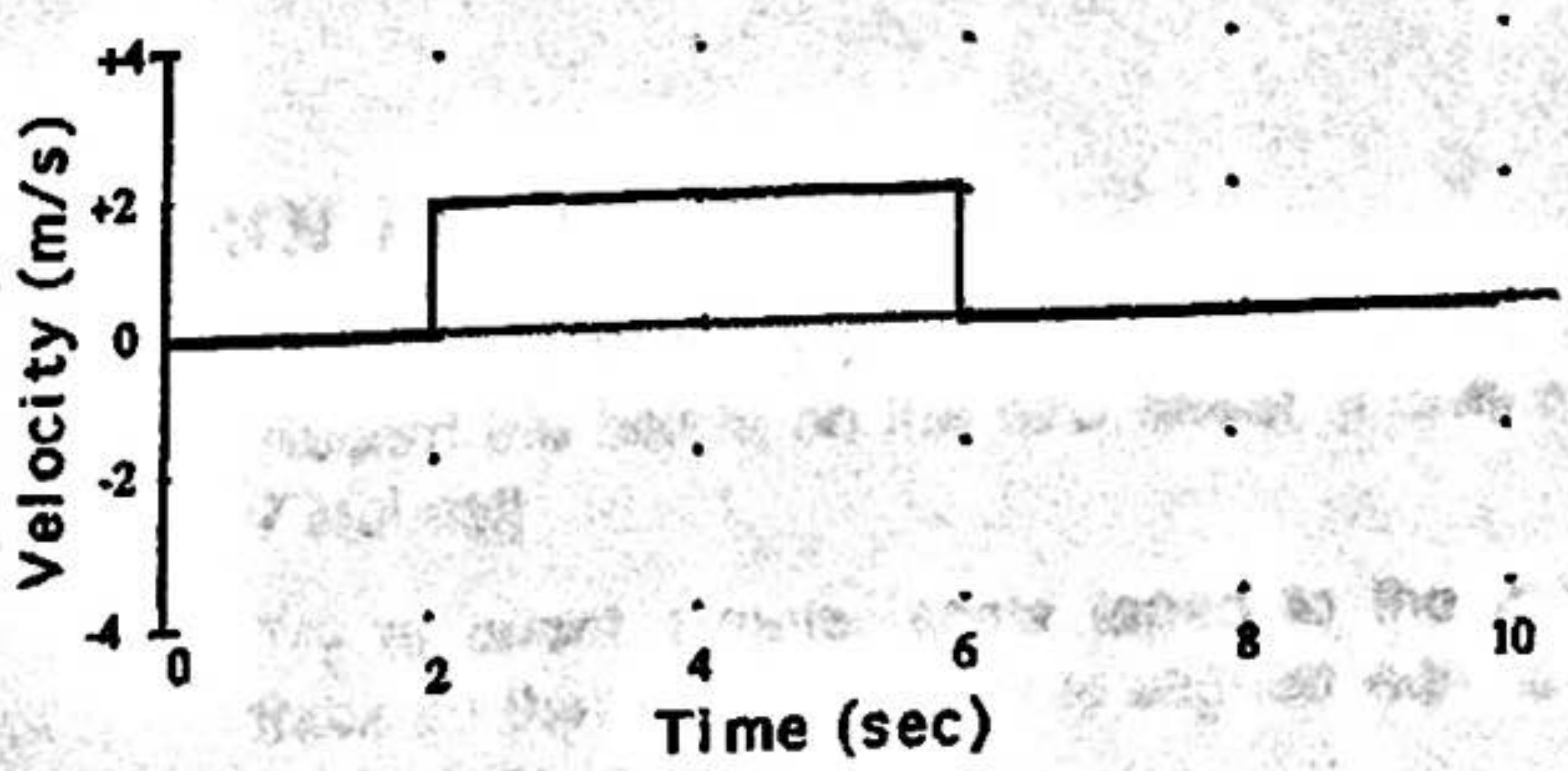
2. Figure out the *distance* the person traveled in the graph below (show your work).

Distance ______________ meters.

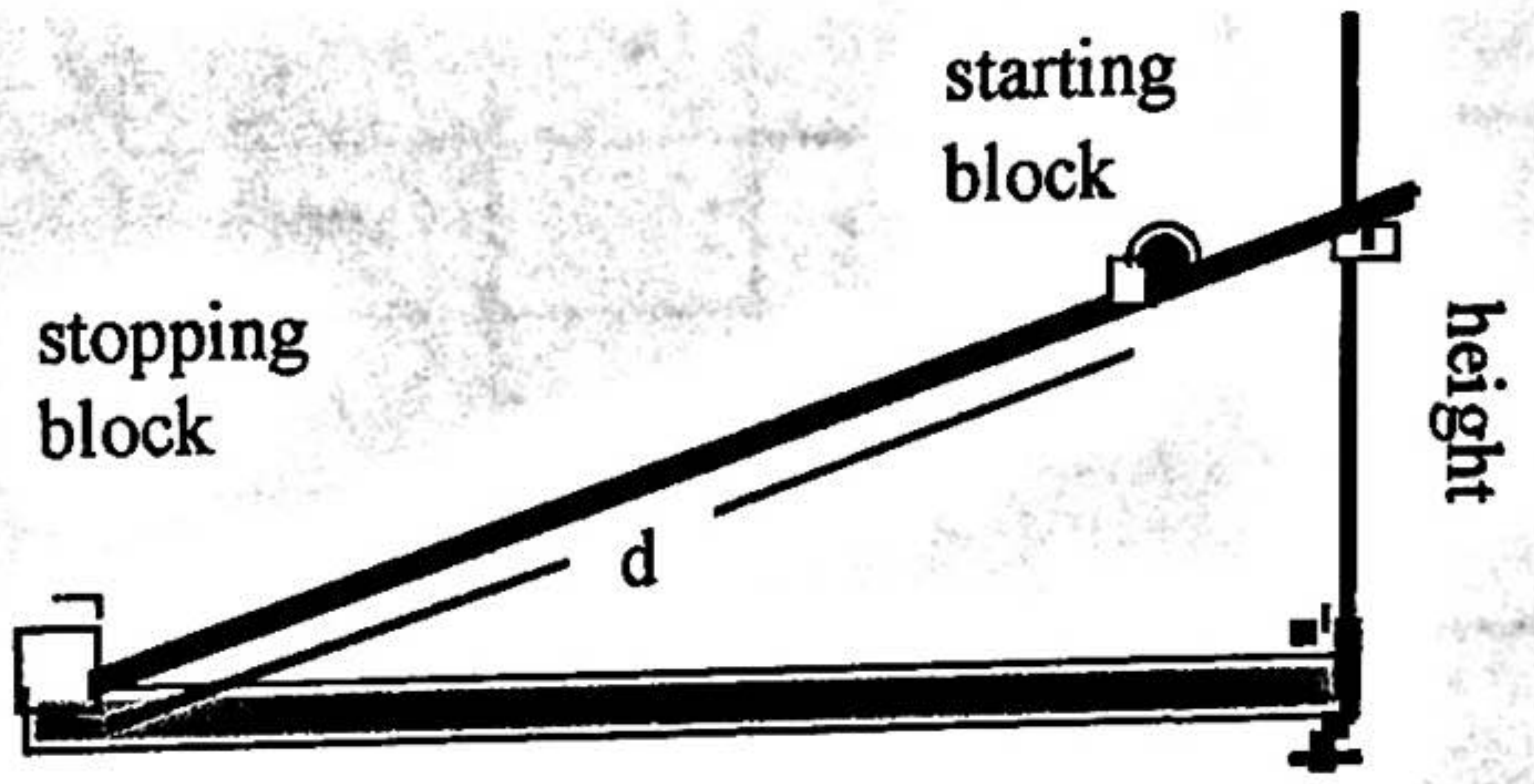


Experiment 3

GALILEO'S INCLINED PLANE and FREEFALL

EQUIPMENT

Graphing program
Galileo program
Averaging values program
1 long rod
1 table clamp
2 balls of like diameter but unlike mass
Motion detector
Lab pro interface
Lab pro power supply
1 aluminum rail track
1 stopping block w/ rubber band
1 stopwatch
1 c-clamp
1 metric ruler
Basketball
Medicine ball
USB cord



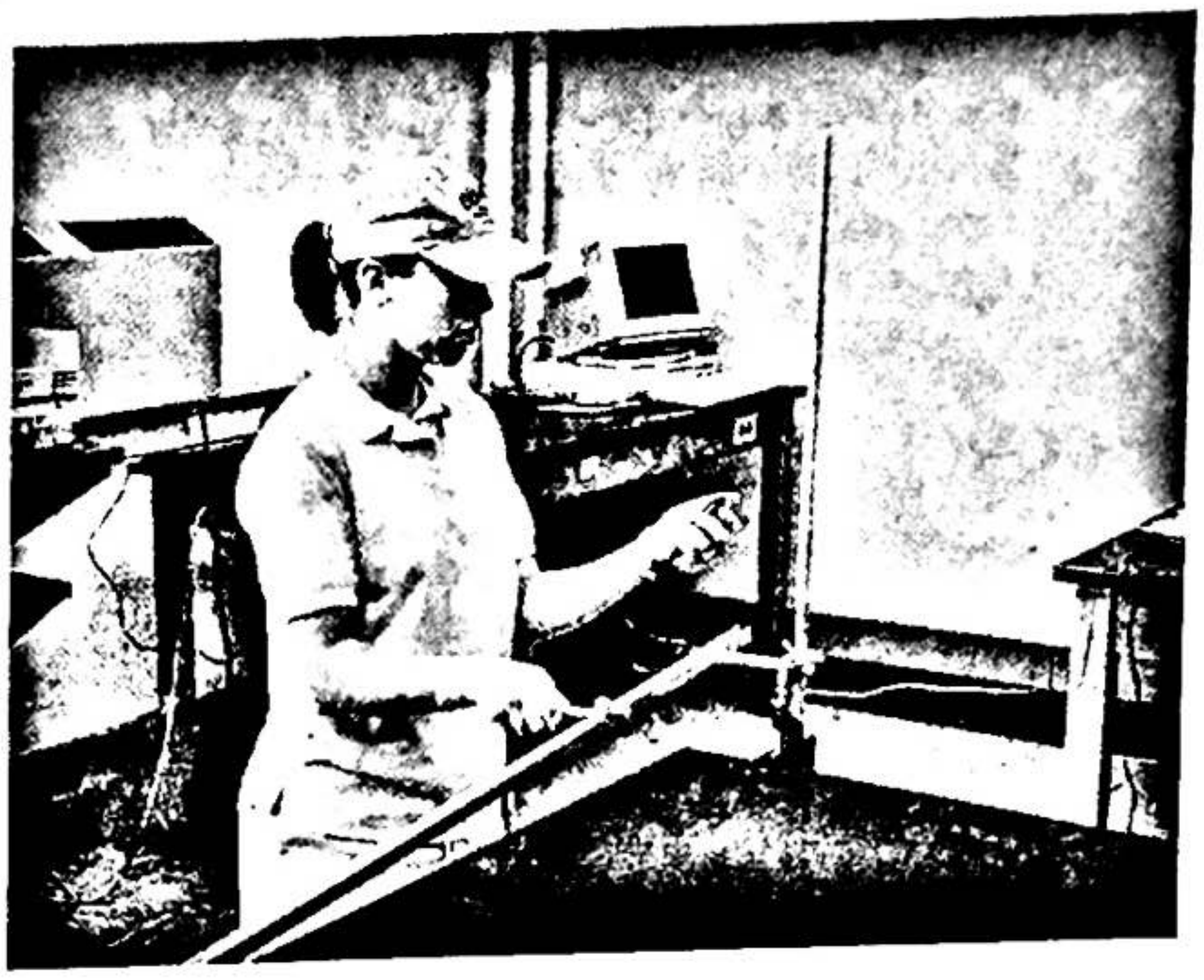
INTRODUCTION

The purpose of this exercise is to recreate an experiment performed by Galileo in the seventeenth century, and show how we can use modern equipment to prove the same hypothesis today.

Using measurements of time and distance Galileo determined the correct relationship between the distance an object falls in an interval of time. Galileo believed that the speed of objects in free fall increases in proportion to the time of fall. In other words, he believed that free falling objects accelerate uniformly. Aristotle, on the other hand, believed that the acceleration is dependent upon the mass.

Since free fall was much too rapid to measure, Galileo looked for another way to investigate free fall acceleration. He made the assumption that a ball rolling down an inclined plane would gain speed in the same way as an object in free fall, only at a slower rate. With this in mind he began working on the relationship between the distance the ball rolled along an incline and the time it took to do so.

He found mathematically that this distance is proportional to the square of the time the ball rolls. Since Galileo's assumption that freely falling objects and rolling balls would accelerate in the same way was correct, this relationship between distance and time also applied to free fall. The equipment available to Galileo could easily measure the quantities of time and distance. Thus he found a way to bypass the difficulties of measuring instantaneous speed.
In this experiment an apparatus (see the illustration) similar to Galileo's will be used. Also, a motion detector will be used to measure the freefall accelerations for a basketball and a racquetball. The data you collect will allow you to decide for yourself if Galileo was correct.



PROCEDURE

1. Verify that the 100cm mark is elevated to 7cm. Record the height on the data sheet. [Caution: Not 7 inches!]

2. Try to orient 1-meter scale taped to the inclined track so that the stop block is aligned with its zero mark at the bottom.

3. Place the steel ball on the incline, at 100 cm from the stop, blocking its descent with a ruler or pencil. This is the distance d, the ball will roll down the incline.

4. Release the sphere by quickly moving the pencil away from it along the incline. Time the descent of the ball with a stopwatch. The end of the descent is best marked by the sound of the ball striking the stopping block. Record the time. Do two more trials with the ball rolling this distance. Record the times in the data chart. **Make sure you start and**

stop the watch in the same manner each time. Check the height of the track and the position of the stopping block after each trial.

5. Repeat steps 3 and 4 for all indicated distances. Don't forget to do three trials for each distance.
6. Use a calculator or the AVERAGING VALUES program to compute the average time taken for each distance. Use the GALILEO program to complete the data table.
7. Refer to Appendix E, Lesson 4. Using GRAPHICAL ANALYSIS construct a graph of time versus distance. This means put distance on the horizontal axis and time on the vertical axis. Print the graph.
8. Construct a graph of time squared versus distance. This means put distance on the horizontal axis and time squared on the vertical axis. Print the graph.
9. Using the plastic ball, note it is much lighter than the steel ball, do three trials from 100cm and average the time it took for the ball to descend. Use the GALILEO program to complete the data table.

CONCLUSIONS

If two quantities are directly proportional a graph of one plotted against the other will be a straight line. Thus, making a graph is a good way to check the relationship between the two quantities.

Experiment 3

DATA SHEET

Name: ______________________

Section: ______________________

Height of raised end = ________________

Distance (d) (cm)			TIMES (sec)	Avg. Time (t) (sec)	Avg. Time squared T^2 $(sec)^2$	Calculated Acceleration cm/sec^2
	Trial 1	Trial 2	Trial 3			
100						
85						
70						
55						
40						
25						
0	0	0	0	0	0	0

Average calculated acceleration for steel sphere = ________________

Distance (d) (cm)			TIMES (sec)	Avg. Time (t) (sec)	Avg. Time squared T^2 $(sec)^2$	Calculated Acceleration cm/sec^2
	Trial 1	Trial 2	Trial 3			
100						

Calculated acceleration for plastic sphere = ________________

Questions-Galileo's inclined plane

1. Which one of your graphs supports Galileo's findings? Be sure and explain why. (See conclusions)

2. Look at the results of the measurements made in step 9. Does the acceleration depend on the mass of the ball? Explain your answer.

3. In what way does your answer refute or support Aristotle's ideas on falling bodies?

4. What are possible causes for your data in step 8 not exactly falling on a straight line? What are the most likely causes of experimental uncertainty in the measurements that you made?

[redacted]

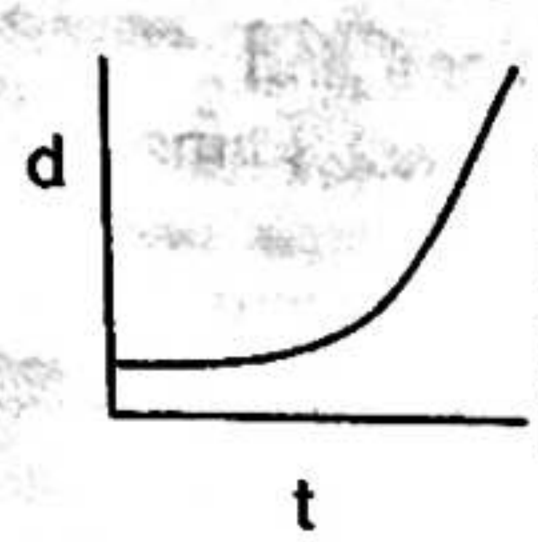
(TURN THIS SHEET IN AS PART OF YOUR DATA SHEET)

B. Freefall

1. Double click on **Exp_3_Freefall.**

The screen will show 3 graphs:

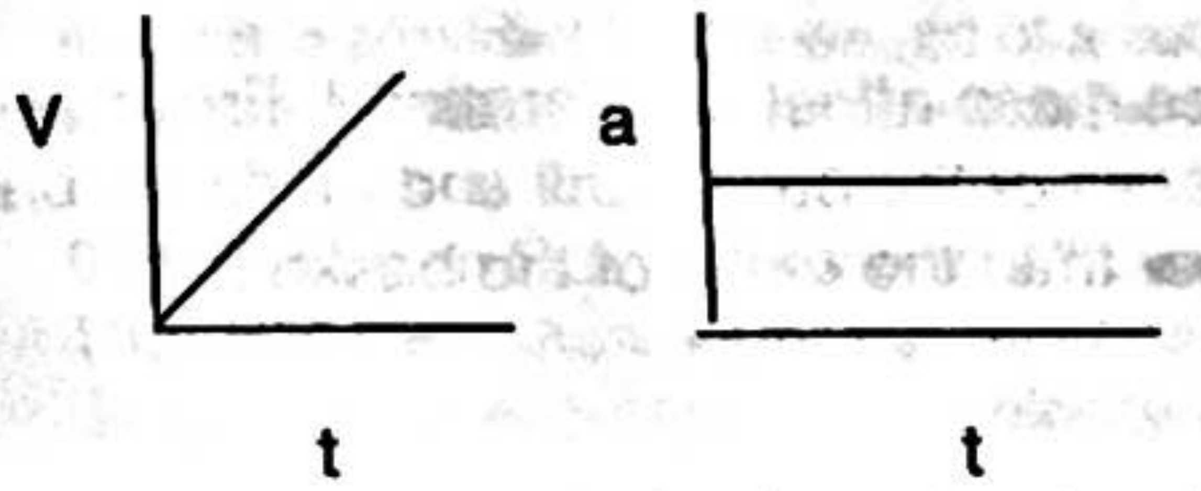
distance vs. time
velocity vs. time
acceleration vs. time.



We remember that a curved line on a distance vs. time graph means that an object is accelerating.

The acceleration can be determined from the acceleration vs. time graph, or by calculating the slope of the velocity vs. time graph. If the acceleration is constant, then the acceleration vs. time graph will make a straight horizontal line and the velocity vs. time graph will make a straight diagonal line.

The entire graph may not show constant acceleration, so look for the parts that match the graphs below. These pieces of the graph show constant acceleration.



The object's velocity is changing, but the rate of change (or acceleration) is constant. We can compare the slope of the velocity graph to the mean (or average) value of the acceleration graph, knowing that they should be equal.

2. Open up **Galileo_Freefall** program.
3. Hold the motion detector at about eye level and hold the basketball about 1/2 a meter below it.
4. Have your partner press the collect button, and then drop the ball (be sure that it's below the motion detector!).
5. When the motion detector has stopped collection, find the portions on your graphs that show constant acceleration (find the parts of the velocity graph that are straight diagonal lines; they will match up with the horizontal portions of your acceleration graph).
6. Change your scale to only show this part of the graph. (Remember: change scale by clicking on the numbers at the end of each axis and typing in the values you desire for starting and ending points on the scale.)
7. Highlight the part of the graph with a constant, positive (or rising) slope.
8. Press the R= button to find the equation of the line. *Remember: $y = mx + b$ where m = slope.* The slope is your value for acceleration. Highlight other parts of the velocity graph that exhibit constant slope (both positive and negative, 2 of each total) tin order to find which one has a value for acceleration that is close to $10 m/s^2$.

Basketball

Values for positive slope:		
Values for negative slope:		

9. Repeat steps 3-8 with the medicine ball.

Rubber medicine ball

Values for positive slope:		
Values for negative slope:		

Questions:

5. Does mass affect acceleration? Prove your answer by discussing the accelerations and masses of the basketball and medicine ball (The mass of the medicine ball is at least 3 times larger than the mass of the basketball).

6. a.) Why are there 2 straight diagonal lines? (*Hint:* What 2 primary actions of the ball is the motion detector recording?)

7. Why do we find the freefall acceleration from the line with positive slope? (*Hint:* remember how moving away from and towards the detector affects velocity!)

8. Label on the velocity graph for just one bounce, or one set of diagonal lines, the 2 points where the ball changes direction (label when it hits the floor and when it reaches the top of its path before falling again. *Hint:* as it changes direction, it must stop for a brief moment, so think of how a velocity graph shows that an object has stopped moving.).

9. 1G is the acceleration of gravity that we normally experience, and is equal to 10 m/s^2. Weightlessness, as in space, is 0G; this is when you would not feel the effects of gravity. Large accelerations, such as are experienced by roller coaster riders, fighter pilots, and astronauts, will give you a higher level of G-force, making you feel the effects of gravity more than normal. Roller coasters, on average, have a G-force near 4G (or 4 times as much gravity as we normally experience) but only for brief moments. Fighter pilots and astronauts can experience longer durations of G-forces as high as 8-9G's.

a.) Divide your value for the negative slope by 10 and see how many G's the basketball is experiencing as it bounces up from the ground. Show work.

_______G

b.) If you could be saddled (strapped) onto a basketball and dropped from 1m, would you want to? Why? Keep in mind that on most roller coaster rides, you experience around 4g, and the most intense roller coasters have a g-force between 5 and 6g's.

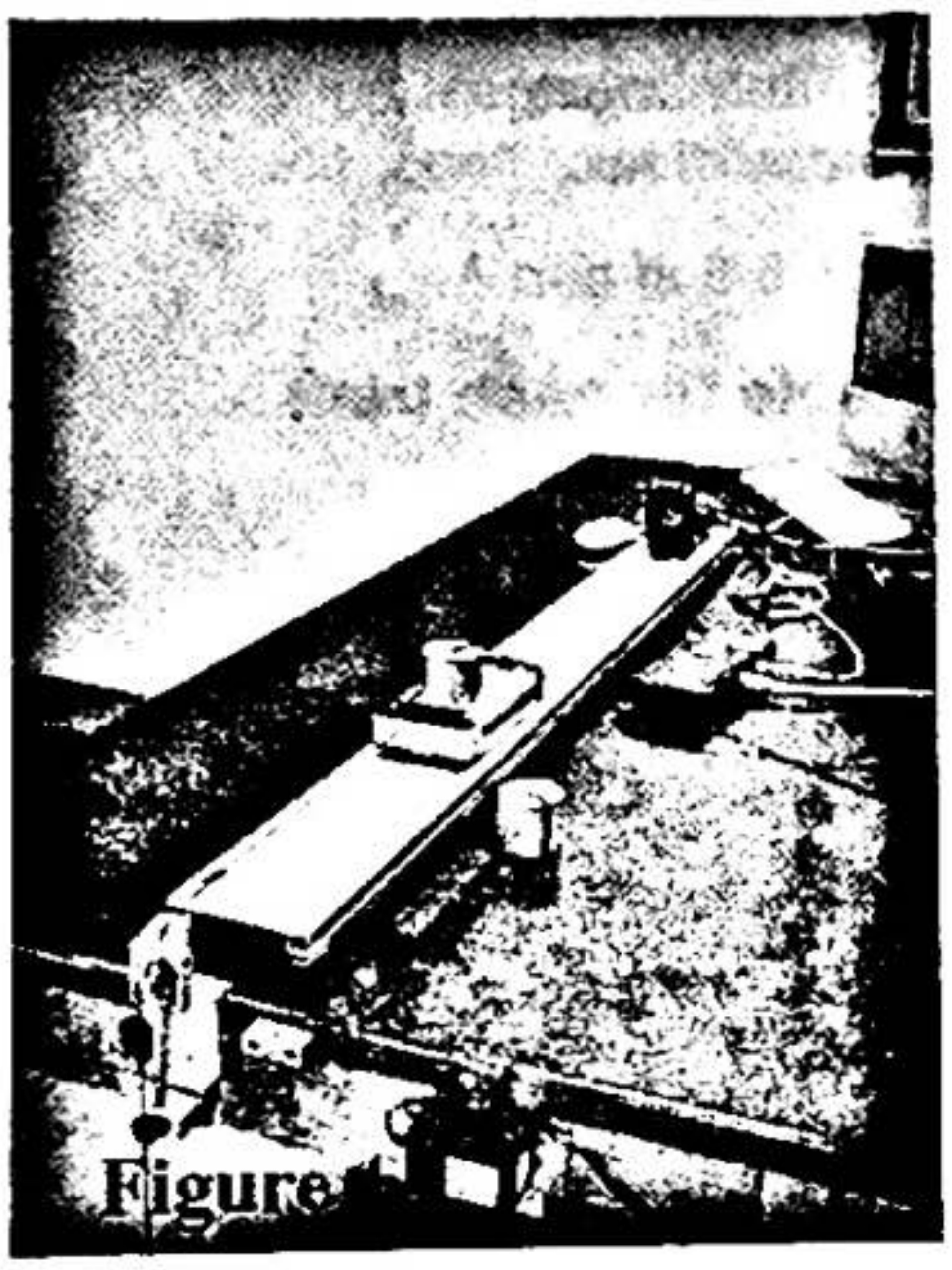
NEWTON'S SECOND LAW

EQUIPMENT

1 connecting string
1 dynamics car
1 dynamic cart track
Newton's 2nd Law Program
Lab Pro interface
- *Power supply*
- *USB cord*

Motion detector
Three 1/2 kg masses for cart
1 table edge pulley
1 set of masses
1 triple beam balance
1 50g mass hanger
1 25g mass

INTRODUCTION



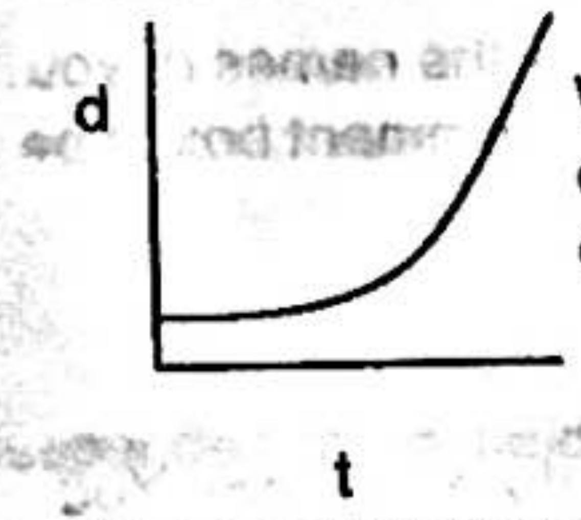
The purpose of this experiment is to examine the motion of an object under the influence of a uniform, or constant, force and to observe the effects of inertia on the motion.

Galileo discovered that objects change their state of motion when acted on by an external force, the velocity of the object changes at a constant rate. Galileo's studies did not adequately explain the relationship between the inertial mass of an object and the force causing the motion. A century after Galileo's discoveries, Isaac Newton was able to explain the relationship between force, mass and acceleration. Newton stated that the acceleration, or rate of change of velocity, is directly proportional to the unbalanced force acting on the object and inversely proportional to the mass of the object. This relationship (known as **Newton's Second Law**) can be expressed as:

$$acceleration = \frac{force}{mass} \quad or \quad a = \frac{F}{m}$$

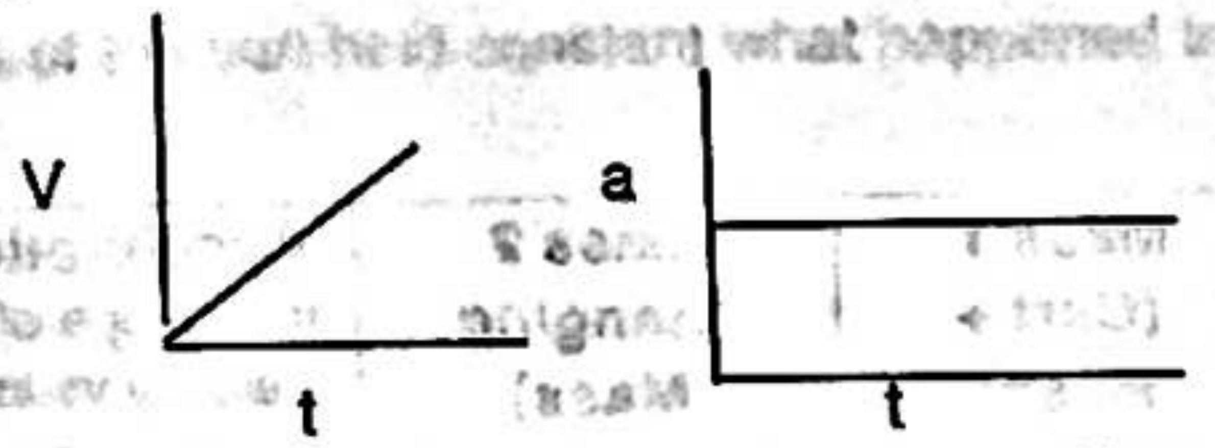
In this experiment you will observe the acceleration of a small cart pulled by a constant force. The force to move the cart is provided by the weight of a suspended mass attached to the cart by a string as shown in Figure 1.

Double click on Exp_5_Newton's 2nd Law folder.
The screen will show 3 graphs: distance vs. time
velocity vs. time
acceleration vs. time.



We remember that a curved line on a distance vs. time graph means that an object is accelerating.

The acceleration of the cart can be determined from the acceleration versus time graph, or by calculating the slope of the velocity versus time graph. The slope of the graph of velocity versus time is the acceleration of the cart. If the acceleration is constant, the slope is constant and a straight line can be drawn through the points.



Any object undergoing motion caused by a uniform force has constant acceleration. The object's velocity is changing, but the rate of change (or acceleration) is constant. We can compare the slope of the velocity graph to the mean (or average) value of the acceleration graph, knowing that they should be equal.

The experiment will be repeated several times, first by varying the mass of the cart and then by varying the force pulling the cart. From the graph obtained for each run, you will investigate the change in the acceleration of the cart when the mass of the cart and the force pulling the cart are varied.

PROCEDURE:

A. Acceleration

1. The mass of the dynamics cart is ½ kg. Add ½ kg to mass cart for a total of 1(one) kg.
2. Set the motion detector at one end of the table and the pulley at the other.
3. Place the cart no closer than 40 cm to the motion detector, and position the string to run over the

pulley. One partner should prevent the cart from moving while the other attaches a 50g mass hanger to the end of the string .

4. Load the NEWTON'S 2nd LAW setup.
5. Press COLLECT and release the cart. Do not allow the cart to hit the pulley.
6. Click the velocity graph, highlight the portion of the graph with a straight diagonal line, and find the equation of the line by clicking the R= button.

   Remember: $y = mx + b$, and m = slope.
7. Click the acceleration graph, highlight the portion of the graph that makes a straight line (this should be the same section that was diagonal for the velocity graph) and find the mean value of acceleration by clicking the STATS button.

   The mean (i.e., average) for the acceleration graph should be equal to the slope for the velocity graph!
8. File > Printing Options and type the names of you and your lab partner, and in the comment box, type M1 = ________, M2 = ________.
9. File> Print.

Print first plot only (check with TA before printing). You should then reproduce the remaining four velocity vs. time plots on the back page of the data sheet. Be sure and record the slope (i.e., the acceleration).

B. Variation of Mass

10. Add 1/2kg to the top of the cart. You have now increased mass of cart by 50%. (What do think should happen to you acceleration?) Repeat steps 5-9 in part A.
11. Add another 1/2kg (now 2 kg total added to cart). What do think should happen to you acceleration?
12. Again repeat steps 5-8 in part A.

C. Variation of Force

13. Remove all additional masses until the cart has a mass of one kg (cart + ½ kg). *The cart should have the same mass as in step one.*
14. Increase the value of the suspended mass by adding 25g. This will *(approximately)* increase the force pulling the cart by 50%.
15. Repeat steps 5-8 in part A.
16. Remove 25g mass from the hanger and add 50g for a total of 100g. *The hanging mass has now been increased by a factor of two.*
17. Again repeat steps 5-8 of part A.

Refer to this table for each trial!

Trial	Mass 1 (Cart + Mass)	Mass 2 (Hanging Mass)	Acceleration from slope of Velocity vs.time (m/s/s)
1	Cart+ ½ kg	0.050 kg	
2	Cart + 1½ kg	0.050 kg	
3	Cart + 1 kg	0.050 kg	
4	Cart+ ½ kg	0.075 kg	
5	Cart+ ½ kg	0.100 kg	

DATA SHEET

Name: ____________________________ Section:____

QUESTIONS

1. **From your velocity versus time graphs, can you conclude that the acceleration of the cart was constant in each case? State your reasons.**

2. **When the mass of the cart was increased and the suspended mass held constant, what happened to the magnitude of the acceleration? Why?**

3. **When the suspended mass was increased and the mass of the cart held constant what happened to the magnitude of the acceleration? Why?**

4. **When the suspended mass was decreased (by a factor of one half) and the mass of the cart held constant what happened to the magnitude of the acceleration? Why?**

5. **Relate the results of your experiment to the statement of Newton's second law.**

6. **If a cart has a weight of 10 N and is pulled by a constant 20 N force, what is the resulting acceleration? HINT: You must distinguish between mass and weight.**

Velocity vs. Time Sketches

(Be sure and include slopes)

Trial 1 (if you did not print out)-

Trial 2-

Trial 3

Trial 4

Trial 5

Experiment 5: Conservation of Momentum

EQUIPMENT

- *Triple beam balance*
- *Two PASCO collision carts*
- PASCO Cart track
- *Amadeus Program*
- Cart launcher
- *Photogate including:*
  1. *Power supply*
  2. *Microphone cord*
- Calculator
- Cart masses
- Digital calipers

Momentum

The purpose of this lab is to observe the conservation of momentum for **inelastic** and **elastic** collisions. Momentum is inertia in motion, and can be calculated by multiplying an object's mass by its velocity (i.e., momentum = mass x velocity).

You have also studied something called impulse (impulse = force x time). Impulse is the change in momentum (i.e., force x time = change in momentum). In order to change momentum, an impulse (i.e., a force acting over some time period) must be applied from outside of the system.

A central law of mechanics is the **conservation of momentum**. This law states, "In the absence of an external force, the momentum a system remains unchanged. In any system wherein all forces are internal-as for example, cars colliding, atomic nuclei undergoing radioactive decay, or stars exploding- the net momentum of the system before and after the event is the same."

In the first part of the lab you will explore the conservation of momentum through an **inelastic collision of two carts**. Inelastic collisions occur when two objects collide and stick together. The initial momentum of one cart plus the initial momentum of the other cart must equal the final momentum of the two cart system once they have collided and stuck together.

$$m_{cart\ a}v_{cart\ a} + m_{cart\ b}v_{cart\ b} = (m_{cart\ a} + m_{cart\ b})v_{cart\ a+cart\ b}$$

If cart B is initially at rest (i.e., $v_{cart\ b} = 0$), then the relationship above becomes

$$\boxed{m_{cart\ a}v_{cart\ a} = (m_{cart\ a} + m_{cart\ b})v_{cart\ a+cart\ b}}$$

In the second part of the lab you will explore the conservation of momentum through an **elastic collision** of two carts. In this case the carts will collide, but they will not stick together. For momentum to be conserved the initial momentum (i.e., before collision) of cart *a* plus the initial momentum of cart *b* is equal to the final momentum (i.e., after collision) of cart *a* plus the final momentum of cart *b*. In equation form this relationship looks like:

$$m_{cart\ a}v_{cart\ a\text{-before}} + m_{cart\ b}v_{cart\ b\text{-before}} = m_{cart\ a}v_{cart\ a\text{-after}} + m_{cart\ b}v_{cart\ b-after}$$

If cart B is initially at rest, then the relationship above becomes

$$\boxed{m_{cart\ a}v_{cart\ a\text{-before}} = m_{cart\ a}v_{cart\ a\text{-after}} + m_{cart\ b}v_{cart\ b-after}}$$

Procedure

Inelastic Collision

1. Set up the photogate on the middle of the PASCO track. Make sure that you adjust the height of the photogates so that the cars can pass under it but the bars still pass in between the sensor. Also, there must be enough room on the track for the carts to pass under the photogates and continue to move down the track.
2. To ensure that the track is level, place one cart in the middle of the track. If the cart starts to roll one way then you need to adjust the level of the track. This can be done by turning a screw on the leg at one end of the track.
3. Use a triple beam balance to measure the mass of both carts. Be sure and turn carts upside down so they do not roll off of the balance when measuring. Record mass in Table 1.
4. Now use a caliper to measure the width of the bars on top of the carts. **Record these values in Table 1**. Please note that Cart A has two bars. See Figure 1 below.

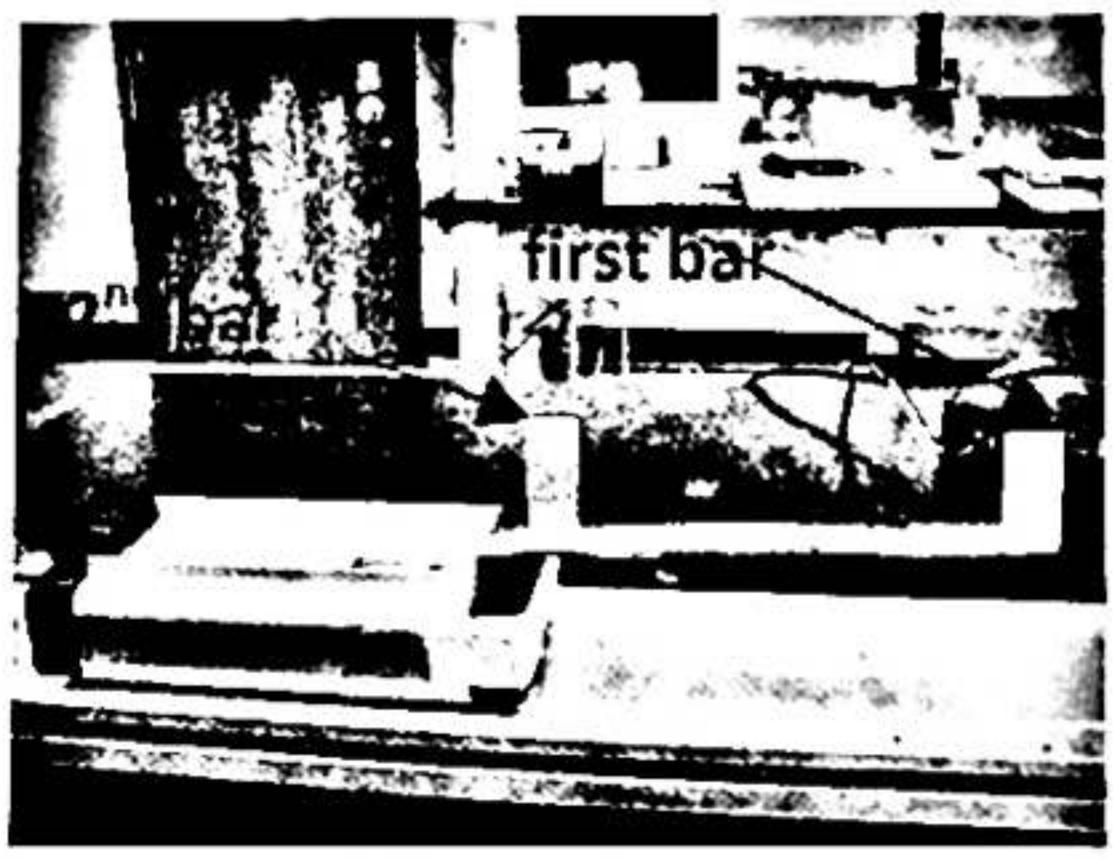


Figure 1

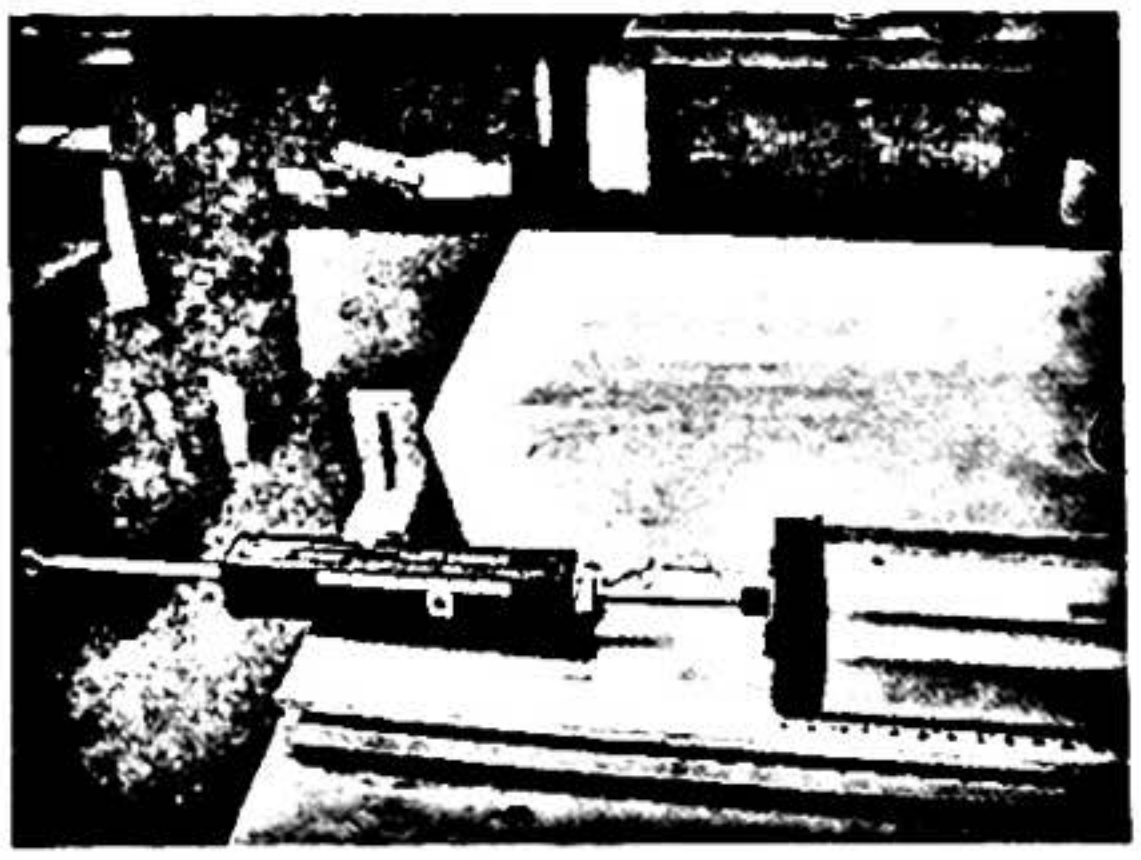


Figure 2

5. Make sure long bar is configured so that the internal magnets are attracted to each other for this part of the lab (i.e., **the carts should stick together when placed end to end.)**
6. Place cart A on the track.
7. Make sure the cart launcher is securely fastened to the track. Push the launcher arm back until it locks into place.
8. Set the cart against the launcher making sure that the wheels of the cart are in the grooves on the track. See Figure 2 above.
9. Now you will use the computer program called AMADEUS to measure the time it takes for the **bar 1** to pass through the photogate. There will be two waveforms displayed. We will ignore the 2nd one for the time being.
10. Begin collecting data on the computer (push "Record" button) and launch the cart by pulling back on the yellow string on the arm that holds it into place.
11. Record the time it takes for the first bar on cart A to pass through the photogate. You can use this number to calculate velocity of cart A. Show one calculation below.

$$velocity = \frac{width \text{ of bar}}{time} = \frac{\qquad\qquad}{} = \qquad\qquad \text{m/s}$$

12. Repeat steps 6-11 once more to ensure that you are getting the same velocity (actually same time) or close a 2nd time.

13. Now you will create an inelastic collision by placing cart B on the track underneath the photogate. See Fig. 3. Note that no bar is necessary on cart B for this part of experiment.

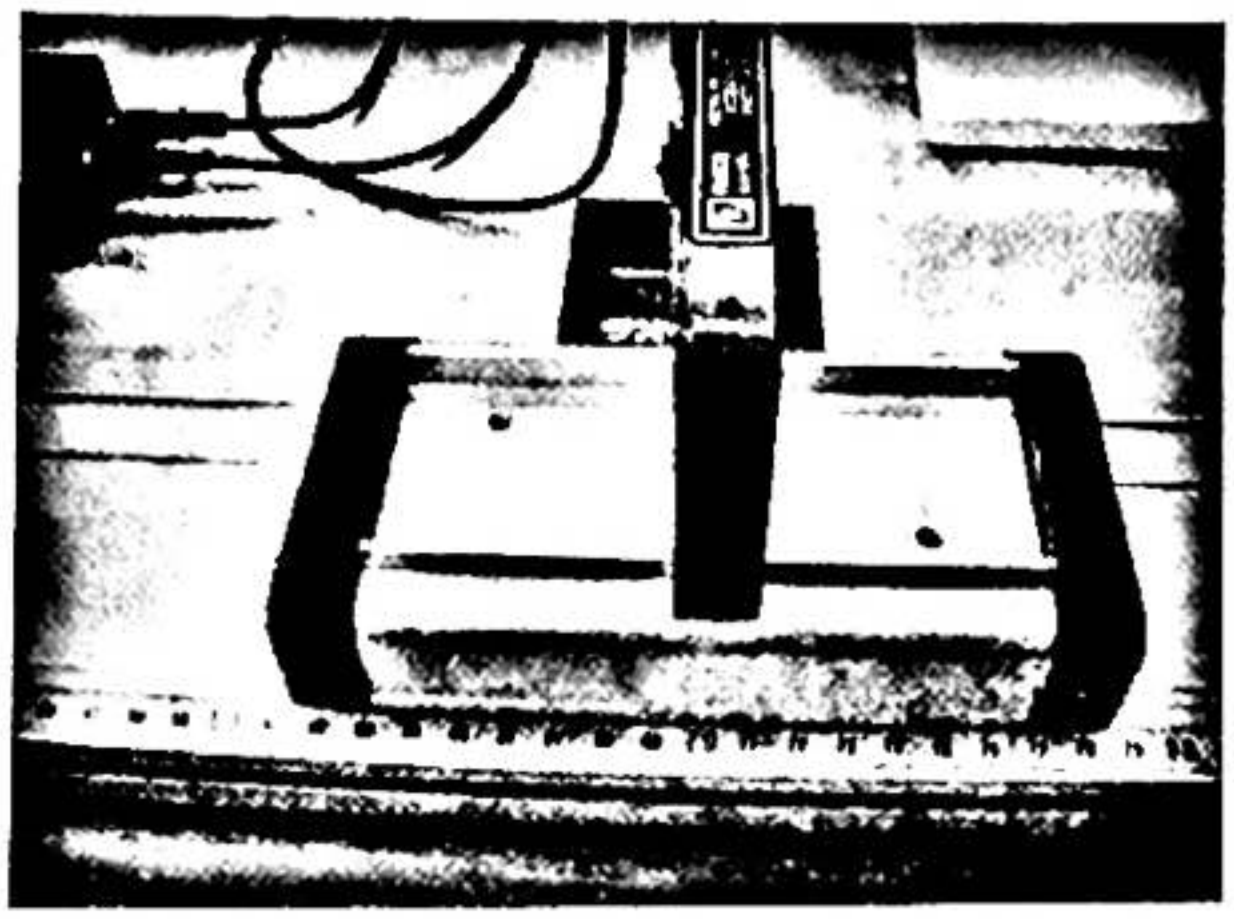


Figure 3. Cart B Inelastic Collision

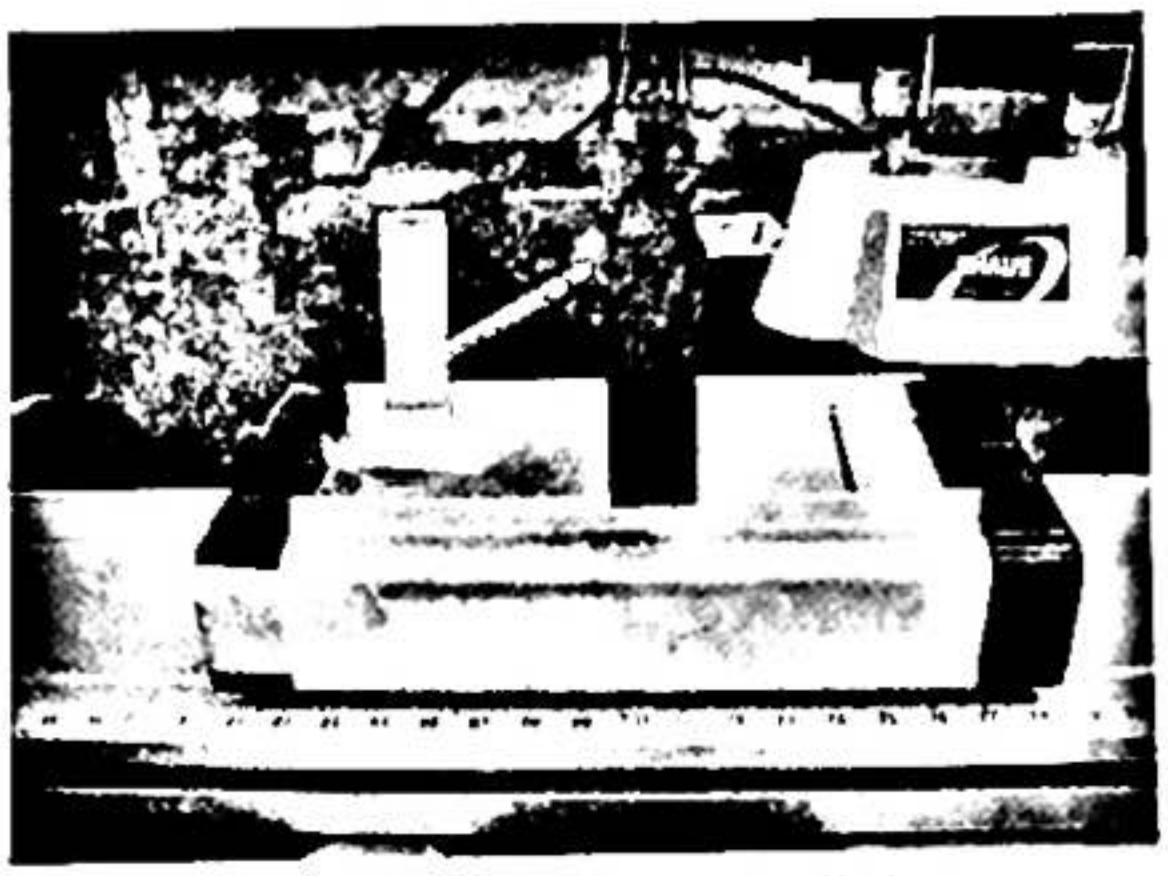


Figure 4. Cart B-Elastic Collision with bar added

14. Now you will use AMADEUS to measure the time it takes for the **both bars** on cart A to pass through the photogate. Please note that as arranged, the first bar on cart A goes through the photogate **before the collision** and the second bar (on cart A) does so **after the inelastic collision.**
15. Arm the launcher, and place the cart back against it. Make sure that cart is up against the plunger before launching. See Figure 2 above again.
16. Once everything is set up **hit record** on your computer. Simultaneously launch the cart. The carts should collide and stick together from the Velcro and magnets.
17. The wave pattern measured by Amadeus should have two signals on it. The first is from bar 1 (which gives the initial or before velocity) and the 2nd is bar 2 (which yields the velocity on *both carts* after the inelastic collision).
18. In tables 2 & 3 record the times it takes for the bars to pass through the photogate (if your cars are of equal mass the 2nd time should be about twice as long as the time measured in step 11.
19. Repeat steps 13-18 to ensure that you are getting the same velocity (or close to it) every time. Record your calculations on your data sheet.

Elastic Collision

20. Now you will observe an elastic collision. Reconfigure (reverse direction of) the bar on Cart A so **the magnets on the carts repel each other when placed end to end.**
21. Now set up the photogate such that it measures the timing of cart A before the collision and both carts after the collision. **Add bar to cart B.** See Figure 4 above. Keep in mind that when you make your calculations your initial velocity of cart B will be zero.
22. Begin collecting data, and launch your cart.
23. Measure the times it takes for cart A to pass through the photogate twice, and measure the time it takes for the cart B to pass through the other photogate once. (Your carts should collide elastically with cart B moving much faster than cart A in same direction.)
24. Calculate your velocities, and record them in data table 4.

Table 1

Cart	Mass of Cart(s) (kg)	Width of Bar 1 on Cart (convert from mm to m)	Width of Bar 2 on Cart (convert from mm to m)
A			
B		Width of Bar 3 here	xxxxxxxxxxxxxxxxxxx
A+B		xxxxxxxxxxxxx	xxxxxxxxxxxx

Inelastic Collision Data

Table 2

Before Collision

Cart A **Cart B**

Trial	measured time in **seconds** for bar 1	Velocity Cart A (m/s) (divide bar 1 width by time)	Momentum kg-m/s		Velocity Cart B (m/s)	Momentum
1					**0**	
2					**0**	
3					**0**	

Average initial (before) momentum=____________________kg-m/s

After Collision

Table 3

Cart A+B

Trial	measured time in seconds for bar 2	Velocity (divide bar 2 width by time)	Momentum kg-m/s
1			
2			
3			

Average initial (before) momentum=__________________kg-m/s

Elastic Collision

Table 4 Before Collision

Cart A **Cart B**

Trial	measured time in seconds for bar 1	velocity Cart A (m/s) (divide bar 1 width by time)	momentum kg-m/s		velocity Cart B (m/s)	momentum kg-m/s
1					0	
2					0	
3					0	

Average initial (before) momentum=__________________kg-m/s

Table 5 After Collision

Cart A **Cart B**

Trial	measured time in **seconds** for bar 2	velocity Cart A (m/s) (divide bar 2 width by time)	momentum kg-m/s		measured time (s) for bar 3	Velocity Cart B (m/s) (divide bar 3 width by	Momentum kg-m/s
1							
2							
3							

Average initial (after) momentum for Cart A=__________________kg-m/s

Average initial (after) momentum for Cart B=__________________kg-m/s

Total momentum after collision__________________ kg-m/s

Elastic Collision with increase Mass of Cart A

25. If time permits, double the mass of cart A and repeat steps 20 through 24 but put data in Tables 6 & 7. Please note that the initial momentum will depend on new mass of cart A.

New mass of cart A (use in table 5 & 6 below) =________________kg

Elastic Collision With Added Masses to Cart A

Table 6 Before Collision

Cart A **Cart B**

Trial	measured time in seconds for bar 1	velocity Cart A (m/s) (divide bar 1 width by time)	momentum kg-m/s		velocity Cart B (m/s)	momentum kg-m/s
1					0	
2					0	
3					0	

Average initial (before) momentum=________________kg-m/s

Table 6 After Collision

Cart A **Cart B**

Trial	measured time in **seconds** for bar 2	velocity Cart A (m/s) (divide bar 2 width by time)	momentum kg-m/s		measured time (s) for bar 3	Velocity Cart B (m/s) (divide bar 3 width by	Momentum kg-m/s
1							
2							
3							

Average initial (after) momentum for Cart A=________________kg-m/s
Average initial (after) momentum for Cart B=________________kg-m/s
Total momentum after collision________________ kg-m/s

Questions

1. Using the results from the experiment, determine whether or not momentum is conserved in each part of the experiment. Is momentum conserved in both (all) parts? If not, give some possible sources of error.

2. What is impulse, and where did you see impulse in this experiment?

3. What's the difference between inelastic and elastic collisions? Is momentum conserved in both? If momentum is not conserved in a collision, what can you conclude?

4. When to cars collide in an automobile accident, what type of collision do the cars (typically) experience? Would it be more damaging to the people inside if the cars stuck together or bounced apart? Why?

5. Picture two astronauts holding on to one another in space (Their initial velocity with respect to each other is zero). If one astronaut pushes the other away, what is the total momentum of both astronauts? If one astronaut weighs (on earth) twice as much as the other, what can you say about the velocity of the less massive one compared to the other?

6. In the last part of the experiment you added mass to the first cart (effectively doubling its mass). Assuming that the spring mechanism acts with the same force over the same time what do you think should happen to the cart's initial velocity? What about its initial momentum? Is this what you observed?

Experiment 6

WORK and ENERGY

EQUIPMENT

Amadeus program
Energy program
*1 photogate**
mini-mini microphone cord
vernier caliper
Inclined track w/ cork
1 Hotwheels ™ race car
1 triple beam balance
Cricket graph
1 Table clamp
1 c-clamp

INTRODUCTION

The purpose of this experiment is to give an object (a toy car) a specific amount of potential energy and determine the velocity and kinetic energy associated with this energy. The relationship between velocity, work, and energy will then be explored. These concepts are summarized below.

Work

Work is defined as force times distance. Thus

$$\text{Work} = \text{Force} \times \text{Distance}$$

or

$$W = Fd$$

For example, you do work when you exert a force on a box that you slide across the floor for some distance. You also do work on a box when you lift it some height above the floor.

Potential Energy

Energy is the capacity to do work. Energy that is a property of position is called *potential energy*. Potential energy due to elevated position is called gravitational potential energy. The gravitational potential energy of a mass at height h is given by

$$\text{Gravitational Potential Energy} = \text{Weight} \times \text{Height}$$

or

$$PE = mgh$$

where the force of weight goes as mass times the acceleration due to gravity.

Kinetic Energy

The kinetic energy of a moving body is equal to one half its mass times its velocity squared or

$$\text{Kinetic Energy} = \tfrac{1}{2}\text{mass} \times \text{velocity}^2$$

or

$$KE = \tfrac{1}{2}mv^2$$

The change in Kinetic energy = work done in bringing object to rest.

Since work is equal to force times the distance through which it is applied, and if friction provides the force, the relationship above becomes:

Change in KE = Frictional Force × Stopping Distance

or

$$\Delta KE = \tfrac{1}{2}mv^2 = Fd\,.$$

This equation relates the energy of a moving car to the stopping distance once brakes are applied. Notice that v is squared. Consequently, *the stopping distance is proportional to the square of the velocity.* **For example, if the velocity is increased by a factor of 2, then the stopping distance increases by a factor of 4!**

This lab utilizes a toy car, an inclined racetrack, a section of track to stop the car, and a computer. You will measure the mass of the car, give it a certain potential energy by placing it at some height above the table, release it, and measure the distance it slides before coming to rest. By measuring its time to travel through a known distance you will calculate the velocity the car.

By graphing the data obtained, you can find out whether the *stopping distance and height* are proportional to the velocity or to the square of the velocity. You will relate the work done in stopping the car to its original velocity and potential and kinetic energies. The primary energy relations examined will be:

ΔPE converted to KE		$mgh = \frac{1}{2}mv^2$
then	or	*then*
ΔKE = Work to Stop		$\frac{1}{2}mv^2 = Fd$

In other words,

$$\Delta PE = \Delta KE = \text{Work to Stop}$$

or

$$\text{mgh} = \tfrac{1}{2}mv^2 = Fd$$

PROCEDURE

1. Measure the mass of your car using the triple beam balance. Record this measurement on the data sheet in kilograms.
2. Note the distance scale along the track. Use this for stopping distance.
3. Set a photogate at the bottom of the track before the cork portion begins to measure the velocity of the car after it has fallen but before it begins to stop
4. Note the three distances marked on the vertical section of the track. These correspond to the measured height column in the data table.
5. Use the Collecting Time Data method as described in Lesson 2 in the Appendix to find the velocity of the car at the position of the photogate. (Measure the width of the tab on the car using a vernier caliper).
6. Line up the center of mass mark on the car with the 0.15m (15cm) height. Press RECORD and release the car.
7. Calculate and record the velocity and stopping distance in the data table. Repeat two more times and record in the data table.
8. Repeat step 6 and step 7 for **0.3m** and **0.6m.**
9. Use a calculator or the AVERAGING VALUES program to find the average velocity and average stopping distance for each of the three heights. Record in the data table.
10. Use the ENERGY program to complete the data table.
11. Plot a graph of stopping distance vs. velocity using CRICKET GRAPH (average stopping distance on the vertical axis and velocity on the horizontal axis).
12. Plot a graph of stopping distance vs. kinetic energy.
13. Plot a graph of velocity vs. height.
14. Plot a graph of and velocity squared vs. *height.*

Experiment 6

DATA SHEET

Width of tab on car = ______________________ m

Mass of car = ________________ kg

$$\text{* Remember: velocity} = \frac{\text{width of the bar on the car}}{\text{time}}$$

Height (meters)	Time (sec)	Velocity (m/sec)	Stopping distance (m)	Potential Energy (Joules)	Avg. Velocity (m/sec)	Avg. Velocity Squared (m^2/sec^2)	Avg. stopping distance (m)	Avg. Kinetic Energy (Joules)
.15								
.15								
.15								
.3								
.3								
.3								
.6								
.6								
.6								

QUESTIONS

1. Look at the graph of stopping distance versus velocity and the graph of stopping distance versus kinetic energy: a) Which graph shows a linear relationship? b) Which shows a non-linear? c) What does this say about the relationship between stopping distance and velocity? Keep in mind that the origin must be considered.

a)

b)

c)

2. Compare and discuss the potential and kinetic energies found during this experiment.

3. What formula was used to find the velocity of the car as it left the vertical portion of the track?

4. A car traveling 50 mph takes 100 feet to stop. How much distance is required to stop it at 100 mph? Show work.

5. Look at the graphs of velocity vs. height and velocity squared vs. height: a) Which graph shows a linear relationship? b) Which shows a non-linear? c) What does this say about the relationship between velocity and height?

a.

b.

c

6. Discuss some possible sources of errors.

Experiment 7

TORQUES

EQUIPMENT

1 meter stick	*1 ERROR program*
1 balance support	*1 sliding knife-edge clamp*
2 mass pans	*2 sliding mass hangers*
1 triple beam balance	*1 set of masses*
calculator	*1 rock with string*

INTRODUCTION

The purpose of this experiment is to study the concepts of center of gravity and torque and to apply these concepts to determine the value of an unknown mass.

A **torque** is the product of a **force** and a **lever arm** distance that tends to produce rotation. The lever arm is the perpendicular distance from the axis of rotation to the line along which the force acts.

The **center of gravity** of an object is the average position of its weight. The force of gravity on the entire object can be considered to act at this point. For instance, the center of gravity of a uniform meter stick would be at its midpoint (the 50-cm mark).

In this experiment you will observe and calculate the torque produced by objects suspended from a meter stick supported at its center of gravity (see Figure 1). The torque produced by each object suspended from the meter stick is found by multiplying its distance from the fulcrum times the force of gravity on that object. In other words:

$$T = F \times D$$

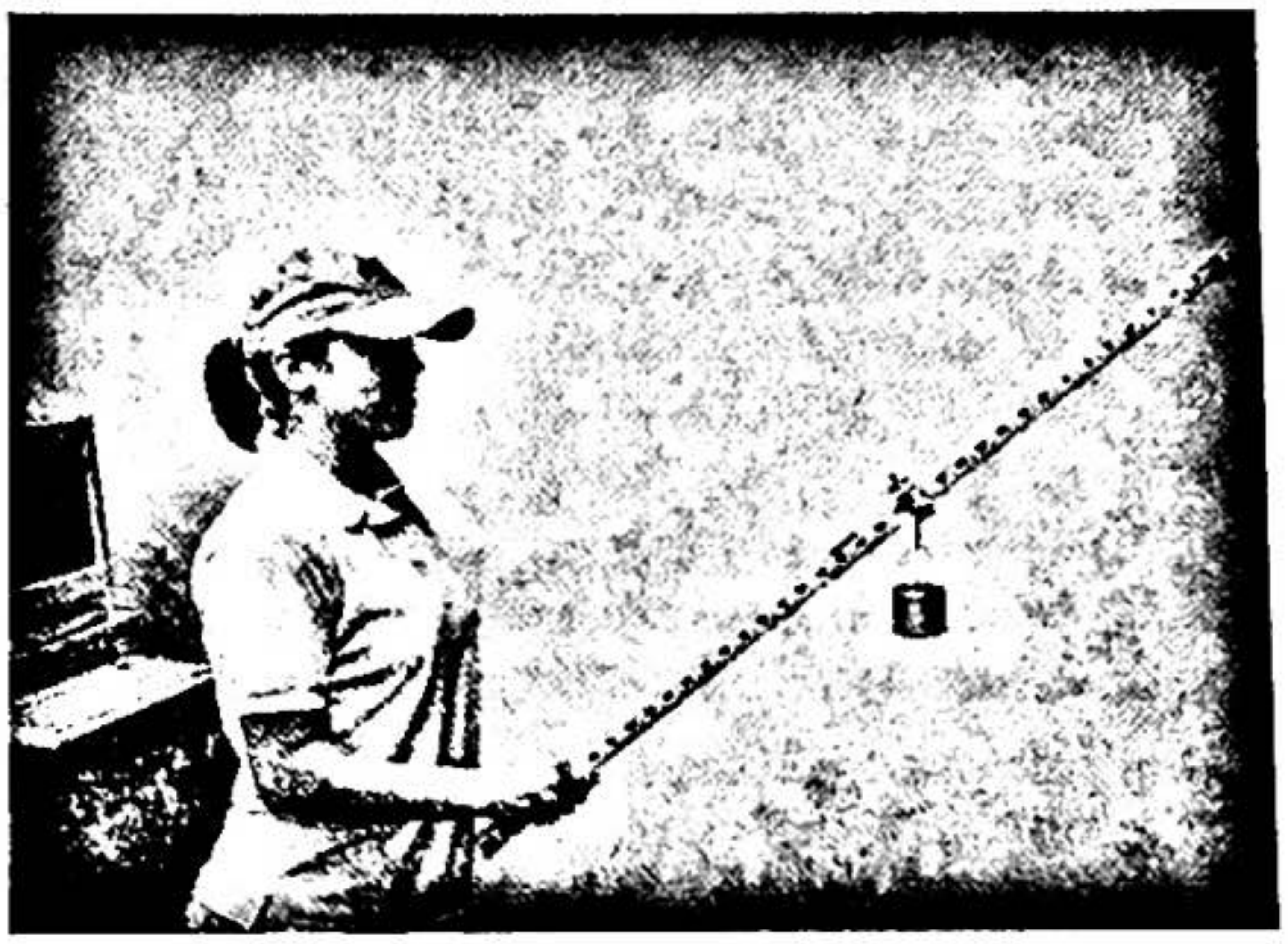
Where D is the distance from the fulcrum.

From your observations and calculations, you will determine the value of an unknown mass and explore the concept of a "solitary seesaw".

PROCEDURE

A. Investigation of Torque

1. Hold a meter stick in your hand near the end marked 0–cm.
2. Place a sliding mass hanger on the meter stick and slide it to the other 20-cm (0.2 m) mark. Suspend a mass pan from the hanger. Place a 500-g (.5 kg) mass on the mass pan and attempt to rotate the stick up and down.



3. Slide the mass hanger with the pan and the 500-g mass to the 40, 60, 80, and then the 95-cm mark. At each mark attempt to rotate the stick up and down. How does the difficulty of holding the meter stick change as the mass is moved away from your hand? Remove the masses and clamp.

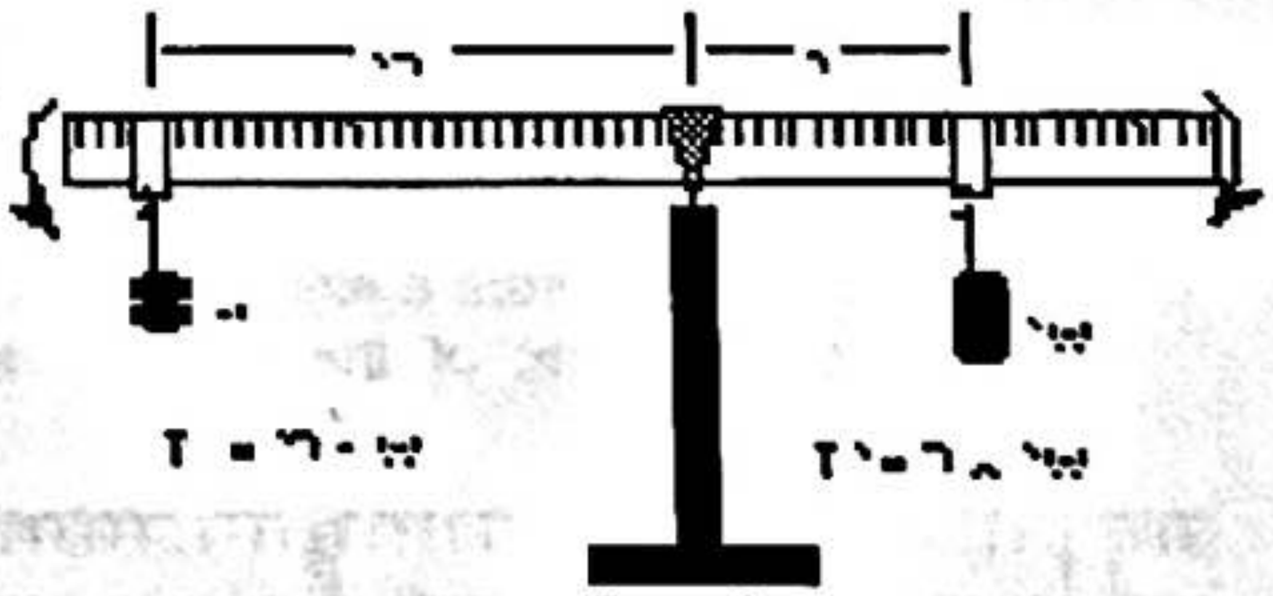


Figure 1

$T1 = T2$

B. Calculation of Torque

4. Slide the knife edge clamp onto the meter stick so that the screw adjustment is at the **bottom edge** of the meter stick (refer to Figure 1). Slide the clamp until it is near the 50-cm mark.
5. Place the knife-edge clamp and meter stick in the balance support. Notice that the clamp serves as a fulcrum and allows the meter stick to rotate. Carefully adjust the position of the clamp until the meter stick is balanced in a horizontal position. This is the position of the center of gravity of the meter stick. This is also the position of the fulcrum when the meter stick is balanced with no additional masses on it. Record this position.
6. Measure and record the combined mass of a hanger, mass pan, and 500-g mass in kilograms. Calculate and record the combined weight.

7. Slide the mass hanger onto the meter stick and position it 20 cm (0.2 m) to the right of the fulcrum. Use the screw to secure the hanger in position. Suspend a mass pan and 500 g (0.5 kg) mass from this hanger.

8. Measure and record the combined mass of the other hanger, mass pan, and 250-g mass in kilograms. Calculate and record the combined weight.

9. Slide the second mass hanger onto the other end of the meter stick and suspend the pan and a 250-g (0.25 kg) mass from it.

10. Adjust the position of the second hanger until the meter stick is balanced in a horizontal position. Record the distance between the position of the hanger and the fulcrum in meters.

11. *Definition*: When the meter stick is balanced in the horizontal position, it is said to be in **equilibrium**. That is, all of the forces and torques cancel one another, resulting in no acceleration.

12. Use the torque formula to calculate the two torques acting on the meter stick. Record the results. Ideally you should find that the torques are equal in magnitude.

C. Determination of an Unknown Mass (see part C on data sheet)

13. Suspend the rock from a string at a position 20 cm (0.2 m) to the right of the fulcrum. Record this distance.

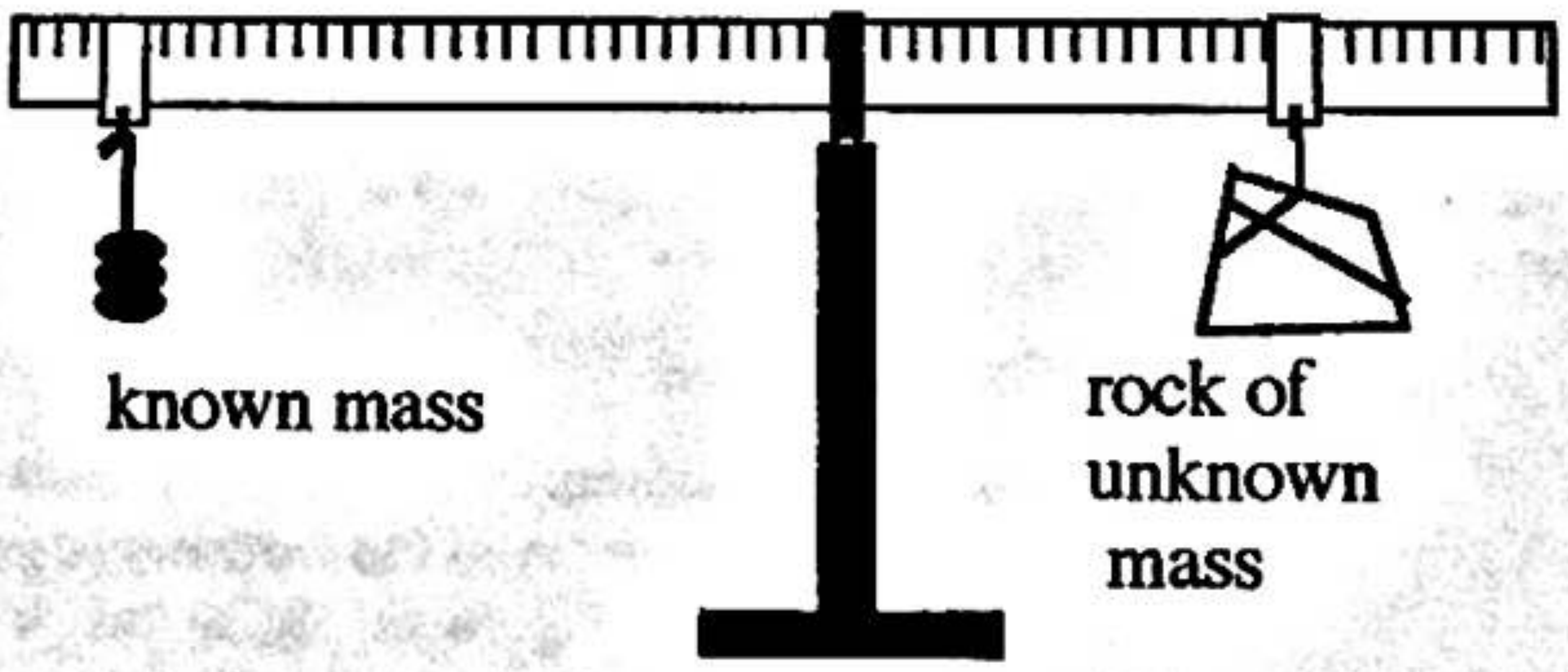


Figure 2

14. a. Measure and record the combined mass of a hanger, mass pan and 100-g mass in kilograms. This is the known mass referred to in Figure 2.

b. Calculate and record the weight of this combination.

15. Slide this mass hanger on the other end of the meter stick and suspend a mass pan.

16. Place the 100-g (0.1 kg) mass on the mass pan.

17. Adjust the position of the hanger until the meter stick is horizontally balanced. At this position, the torque produced by the known mass is equal to the torque produced by the rock and its hanger. Record the distance between the hanger and the fulcrum in meters.

18. Use the torque formula to find the torque caused by the known mass. Record the result.

19. Below is an equation that shows how one calculates the weight of the rock and hanger given the known weight and length of each lever arm.

20. Make sure you understand how this equation was derived. In general,

Torque = Weight × Length of lever arm

or

$$T = WL.$$

Because the meter stick is in equilibrium, we know the magnitude of the torques are equal and oriented in opposite directions, so

$$T_{\text{Known}} = T_{\text{rock}}$$

Using our general definition of torque,

$$W_{\text{Known}} \times L_{\text{Known}} = W_R \times L_R \,.$$

Finally, we solve for the weight,

$$W_R = \frac{W_{Known} \times L_{Known}}{L_R}.$$

21. a.) From this equation, calculate the weight of the rock with its hanger. Record this weight. b.) Then calculate and record the mass of the rock and its hanger.

22. Use the triple beam balance to find the mass of the rock and hanger. Record the result.

23. Use the ERROR program to find the percent error as compared to the mass found with the triple beam balance, using the triple beam balance as the true value.

D. Investigation of a "Solitary Seesaw"

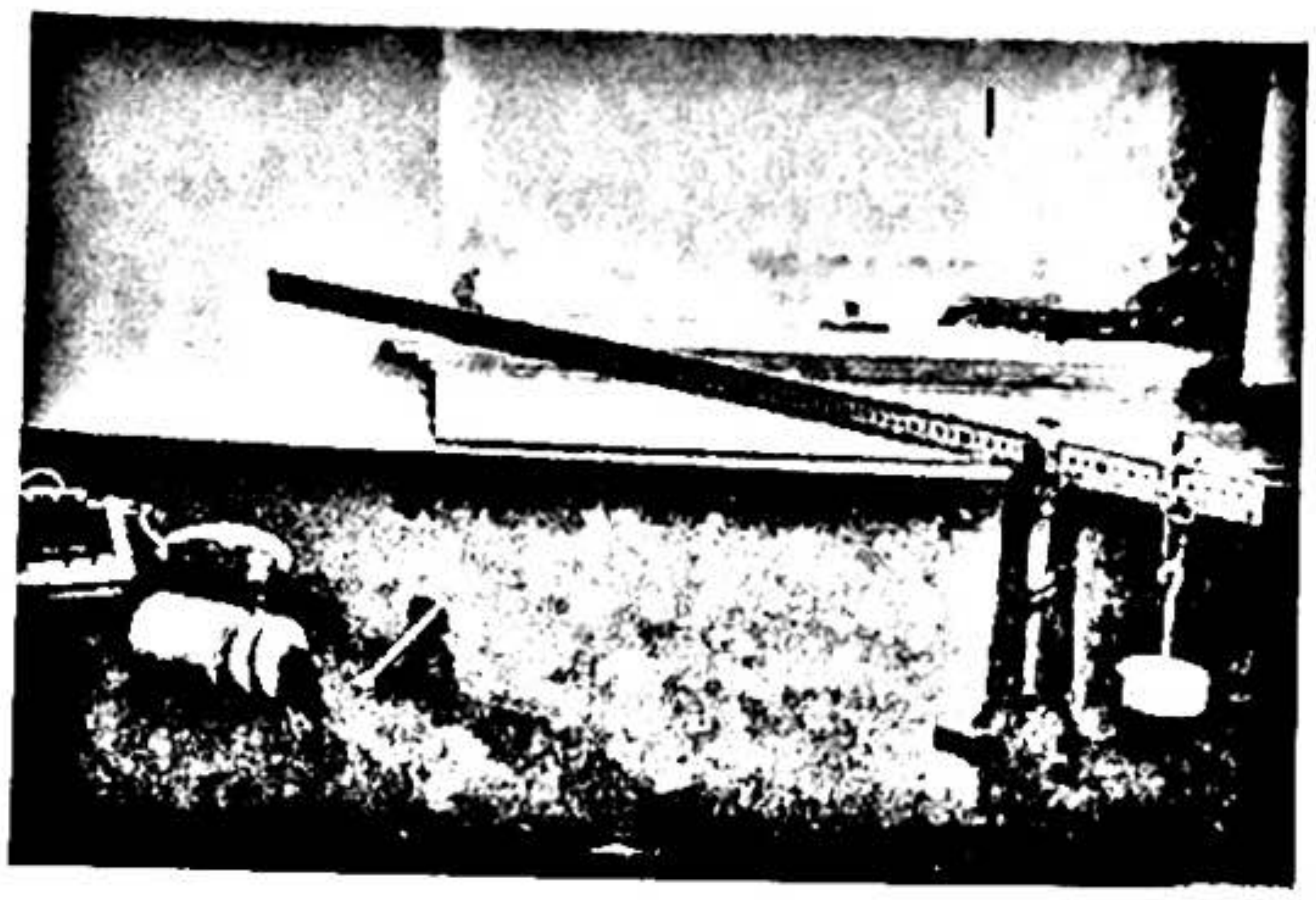


Figure 3

24. Use the triple beam balance to determine the mass of your meter stick. Record this mass in kilograms.

25. Slide the knife-edge clamp onto the meter stick and position it near the 90-cm mark. Tighten the screw.

26. Place a knife edge clamp and meter stick in the balance support. Notice that the meter stick does not balance with the fulcrum in this position.

27. Slide a mass hanger onto the meter stick and securely position it at the 95-cm mark. Suspend a mass pan from the hanger. Place a 200-g (0.200 kg) mass on the pan.

28. Loosen the screw on the knife edge clamp and adjust the position of the fulcrum until the meter stick is horizontally balanced. Record the position of the fulcrum and the distance between the fulcrum and the mass hanger.

Experiment 7
DATA SHEET

Name: ____________________

Section: ____________________

A. Observations: As you slide the mass further down the meter stick, how does the difficulty of holding the meter stick change?____________________

____

____

B. Calculation of Torque

position of fulcrum = ____________cm mark

Combined mass of hanger pan, and mass (kg)	combined weight (N)	distance from fulcrum (m)	Calculated Torque (N*m)

C. Determination of an Unknown Mass

Step13: distance from rock and hanger to fulcrum ____________m

Step 14 a: known mass of hanger, pan, and 100g ____________kg

Step 14 b: known weight of hanger, pan, and 100g ____________N

Step 17: distance from known mass to fulcrum when balanced ____________m

Step 18: calculated torque caused by known mass ____________N * m

Step 21 a: calculated weight of rock and mass hanger ____________N

Step 21 b: calculated mass of rock and mass hanger ____________kg

Step 22: mass of rock and mass hanger measured by triple beam balance ____________kg

Step 23: percent error of calculated mass of rock and hanger ____________%

D. Investigation of a "Solitary Seesaw"

mass of meter stick _______________ kg   final position of fulcrum _______________ cm mark

distance between fulcrum and mass ____________ cm

QUESTIONS

1. Define torque and draw a diagram that illustrates the definition, labeling where the fulcrum is located and where the distances are measured.

2. In part A, why did it become more difficult to rotate the meter stick each time you repositioned the mass?

3. After the meter stick was balanced in part B, the system was in **equilibrium**. Define equilibrium. Since forces were acting on the meter stick, explain why the meter stick was in equilibrium.

4. In part D, there was a mass placed on one side of the fulcrum that caused a torque. When the fulcrum was positioned so that the system was in equilibrium, there must have been a second torque to counteract the first. What produced this second torque?

5. At what position along the meter stick did this torque act?

6. A mass of 1 kg is located at the 0-cm end of the meter stick. If the meter stick is suspended at its center, what mass must be placed at the 75-cm mark to balance the stick?

7. Why is it easier to open a door by pushing on the edge of the door nearer the knob than the hinges?

8. Identify a measurement device we have been using in this laboratory that makes use of torque. Draw a picture of the device identifying the fulcrum and lever arm distances.

Experiment 8

Gravity

Equipment

Pair of magnets
Magnetic force apparatus-(tube with slit attached to wood base)
Bathroom scales
Ruler
Digital balance
Mass set
Calipers

INTRODUCTION

Sir Issac Newton did not discover gravity. What Newton discovered was that ***gravity is universal***-that it is not unique to earth, as others of his time assumed.

The ancients believed that the stars, planets and the Moon move in devine circles which were free from any "impelling forces". Newton recognized that a force of some kind must act on the planets and that this *force must be directed towards a fixed central point* – the sun.

Newton's intuition *(a single set of laws for earth and the the heavens)* was a revolutionary idea and is manifested in his **law universal of gravity** which states that everything pulls on every thing else in a way that involves only mass and distance. This can be expressed symbolically as

$$Force \sim \frac{mass_1 \times mass_2}{\text{distance}^2} \text{ or } F = G\frac{m_1 \times m_2}{\text{d}^2}$$

where m_1 and m_2 are the masses of the two bodies and d is the **distance between their centers.** G is the *universal gravitational constant* with an experimentally determined value of $6.67 \times 10^{-11} N \cdot m^2 / kg^2$.

The value of G indicates that gravity is a very weak force-the weakest of presently known four fundamental forces.

Gravity and distance are related by what is known as the **inverse square law** where *the effect of a localized source spreads uniformly throughout the surrounding space.*

When you step on a bathroom scale you compress a spring. When the pointer stops, you and the scale (i.e., the spring) are in static equilibrium. If you stand on a scale while in an elevator you will find that your weight varies as the elevator accelerates up or down. If the cable breaks and the elevator falls freely, your weight (according to the spring scale reading) will be zero. **Are you weightless?**

To answer this question we must first define what we mean by weight. A 'broad' definition of weight is the *force exerted by the object "against a supporting force or a weighing scale".* **According to this definition you are as heavy as you feel.** You would thus be weightless in a freely falling elevator (even though there is still a gravitational force acting on you).

The earth and the moon pull on each other (even though they do not touch) through a mechanism called *action at a distance.* We can regard the moon as interacting with the gravitational field of the earth. The properties of the space surrounding any massive body can be considered to altered in such a way that another body with mass in this region experiences a force.

A gravitational field is an example of a force field. Other examples are the electric and the magnetic fields.

Projectile Motion-Without gravity, you could toss a rock at an angle skyward and it would follow a straightline path. Because of gravity, however, the path curves. See figures 10.6, 10.7 and 10.8 of text. *A tossed object (e.g., a ball, rock or cannonball) that is projected by some means and continues in motion by its own inertia is called a projectile.*

The weight and mass of you and your cell phone

Students are commonly confused about the difference between mass and weight and the proper units of each. Part of the confusion stems from the fact that in the United States the *quantity of matter* is commonly described by its weight (with common units of *pound force* or lb_f) and in most of the world the *quantity of matter* is described by its mass with units of kg. The units of force in the SI system is the newton. **Please note that henceforth, "pounds" refers to "pound force".**

In this exercise you will: 1) convert your weight in pounds from a **bathroom scale** and convert to both mass and weight in SI units, 2) measure your cell phone's mass on a **balance** and convert to its weight in SI units. An example follows.

Weight on bathroom scale = 165 pounds

Convert to mass in SI units-

$$165 \text{ pounds} \times \frac{1\ kg}{2.205 \text{ pounds}} = 74.8 \text{ kg}$$

Convert to to (SI)weight

$$\textbf{Weight} = 74.8 \text{ kg} \times \frac{9.80\ N}{1 \text{ kg}} = 733.3 \text{ N}$$

Mass of cell phone = 108.28 g
= 0.10828 kg

Convert to weight in SI units

$$0.10828 \text{ kg} \times \frac{9.80\ N}{1 \text{ kg}} = 1.06 \text{ N}$$

Weight of cell phone = 1.06 N

Repeat the calculations above in the data section using your weight and the mass of your cell phone. If you do not have a cell phone use a mass of 100g. *If you have qualms about revealing your weight, use the weight that you would like to weigh.*

The look of gravity (in a uniform gravitational field e.g., surface of earth).

Gravity's Rainbow is a postmodern novel written by Thomas Pynchon and first published in 1973 was a winner of the national book award. The novel's title is a reference to the parabolic trajectory of a (World War 2) V-2 rocket as it moves under the influence of (only) gravity after its engine stops firing (air resistance notwithstanding).

While the fact that projectiles move in parabolic paths is known by all physicists and some writers, Hollywood moviemakers seem to be totally ignorant of this fact as well as the laws of the conservation of momentum, conservation of energy and Newton's Third law (of action-reaction).

In this section of the experiment projectile motion and how it really looks is examined with particular focus on a Hollywood movie or two.

First –You estimate the actual path of a projectile using very simple math and the basic knowledge of how a projectile actually behaves. The steps are as follows:

- **Draw a straight line** extending from (and parallel to) the barrel of the ballistic pendulum to the vertical meter stick (see Figure 10.8 from text below).

- Using the time of flight given and the equation $\text{distance} = \frac{1}{2}gt^2$ or $\text{distance} = 5t^2$, **determine the distance** the projectile should fall.

-**Indicate this distance** on the vertical meter stick

Second – You will use the knowledge above to make predictions about a real projectile on figures two and three below. Your TA will then show you a video of a real ball being projected to examine how your predictions compared to experiment.

Third - Your TA will show a clip (or clips) from a movie featuring projectile motion and you will analyze and discuss.

The feel of gravity- The inverse-square law

(Why black holes 'suck' so hard)

The force of gravity obeys the inverse square law while **magnetic force** effectively obeys what is called **the inverse cube law. Because gravity is so weak we will use magnets** to examine the behavior of the force (i.e., 'the feel') of gravity.

Although gravity and magnets obey different force laws, they are similar enough to explain **why a pair of strong magnets will forcefully pinch your finger if you are not careful** and why a black hole has a gravitational attraction that can be so intense that even light cannot escape. See figure five below.

Procedure

1. Measure the mass of the weight platform and the aluminum rod on your table. See figure 6 below. Put mass values in data table 1 and convert to force.

2. Measure the distance between the top on the lower magnet and the top of the bottom magnet. Initially the magnets will be slightly tilted. They will straighten up when more mass is placed on them. See figure 6 on the right. Put this starting distance in first row of data table 1.

3. Place the short alumium rod inside the tube on top of the magnets and remeasure the the distance. Record mass and new distance in table 1. Remove short. Repeat for longer rod.

4. Remove the rod and replace with the weight holder apparatus. Record mass and new distance of the magnets in table 1.

5. Add mass to the weight holder until the magnets almost touch. Record all masses and distances in table 1.

6. Plot force vs. distance using **Graphical Analysis** software. Curve fit

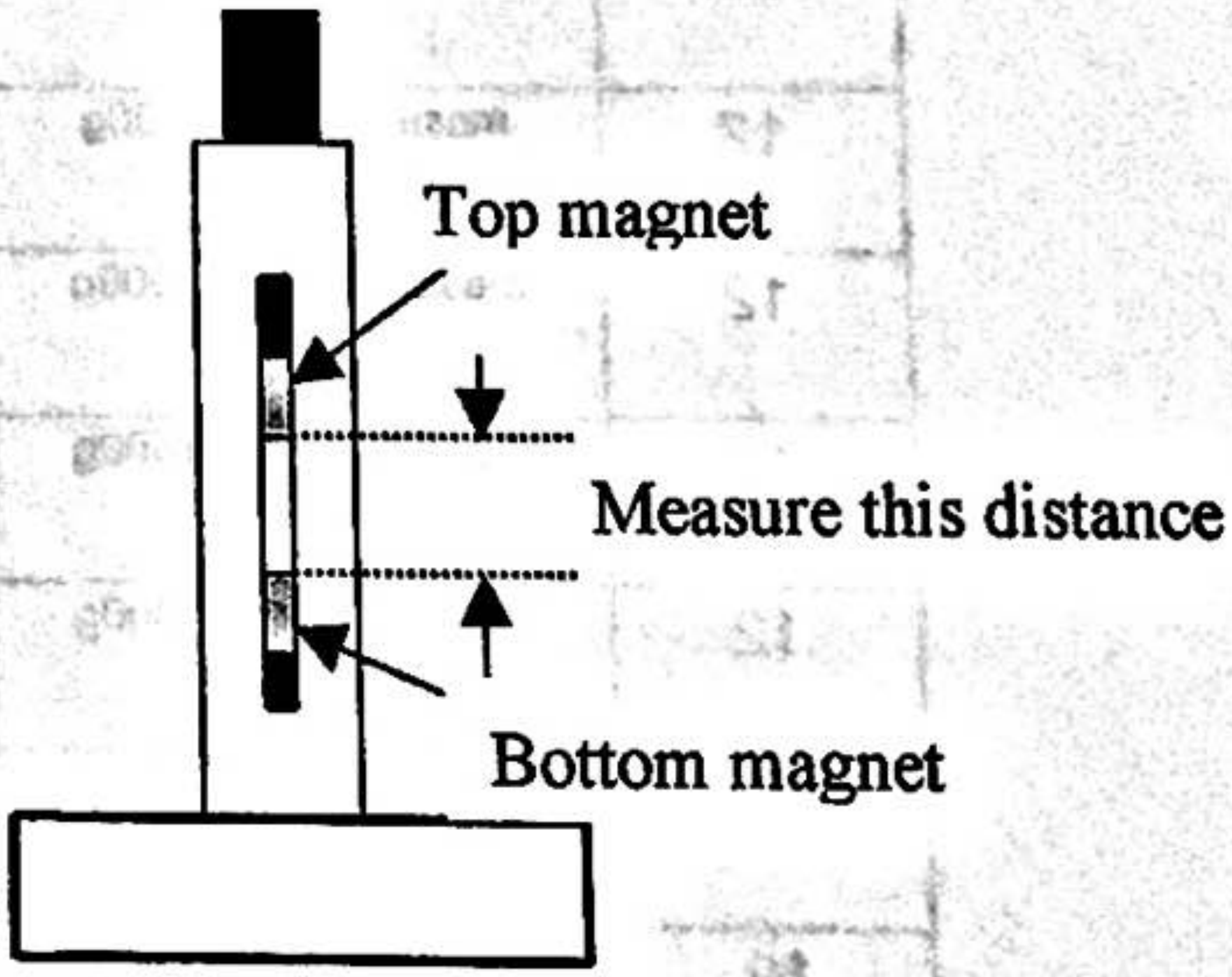


Figure 6

Data

Weight on bathroom scale = ________
Show all calculations below

Your weight (SI units) = ____________

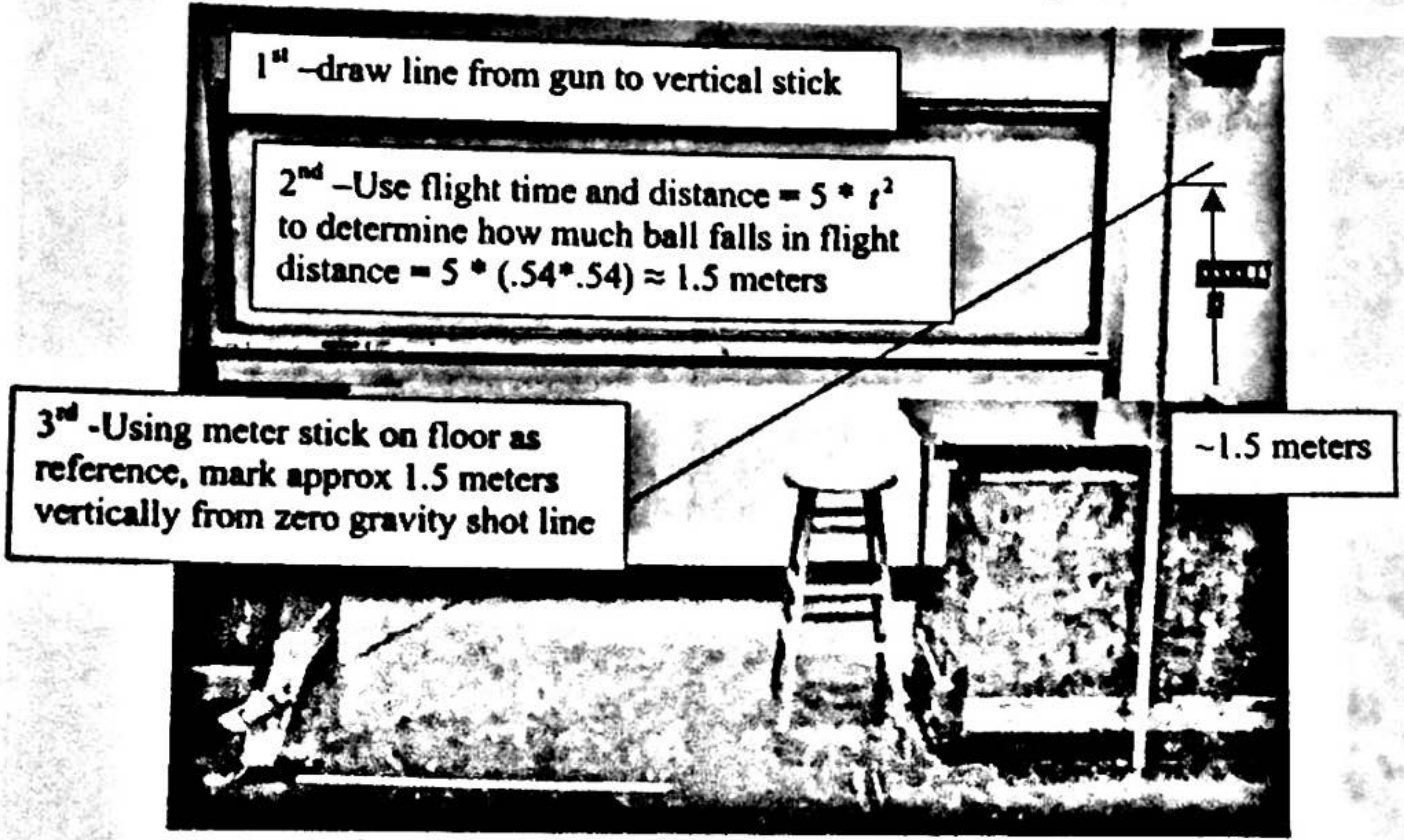
Mass of cell phone = ______________

Weight of cell phone = ___________

The Feel of Gravity Data Table

mass of magnet (g)	mass of what is on top of magnet (g)	Total mass (grams) [sum of columns 1 & 2]	Total mass (kg)	Force (use g =10 m/s/s/) (N)	distance (cm)
12	magnet only	12	0.012 kg	0.12	
12	short rod				
12	long rod				
12	mass platform only				
12	mass platform+500g				
12	mass platform+1000g				
12	mass platform+1500g				
12	mass platform+2000g				
12	mass platform+2500g				
12	mass platform+3000g				
12	mass platform+3500g				

The Look of Gravity



1st –draw line from gun to vertical stick

2nd –Use flight time and distance = 5 * t^2 to determine how much ball falls in flight distance = 5 * (.54*.54) ≈ 1.5 meters

3rd -Using meter stick on floor as reference, mark approx 1.5 meters vertically from zero gravity shot line

~1.5 meters

Figure 1- Time of flight to vertical (2 meter) stick = 0.54 seconds

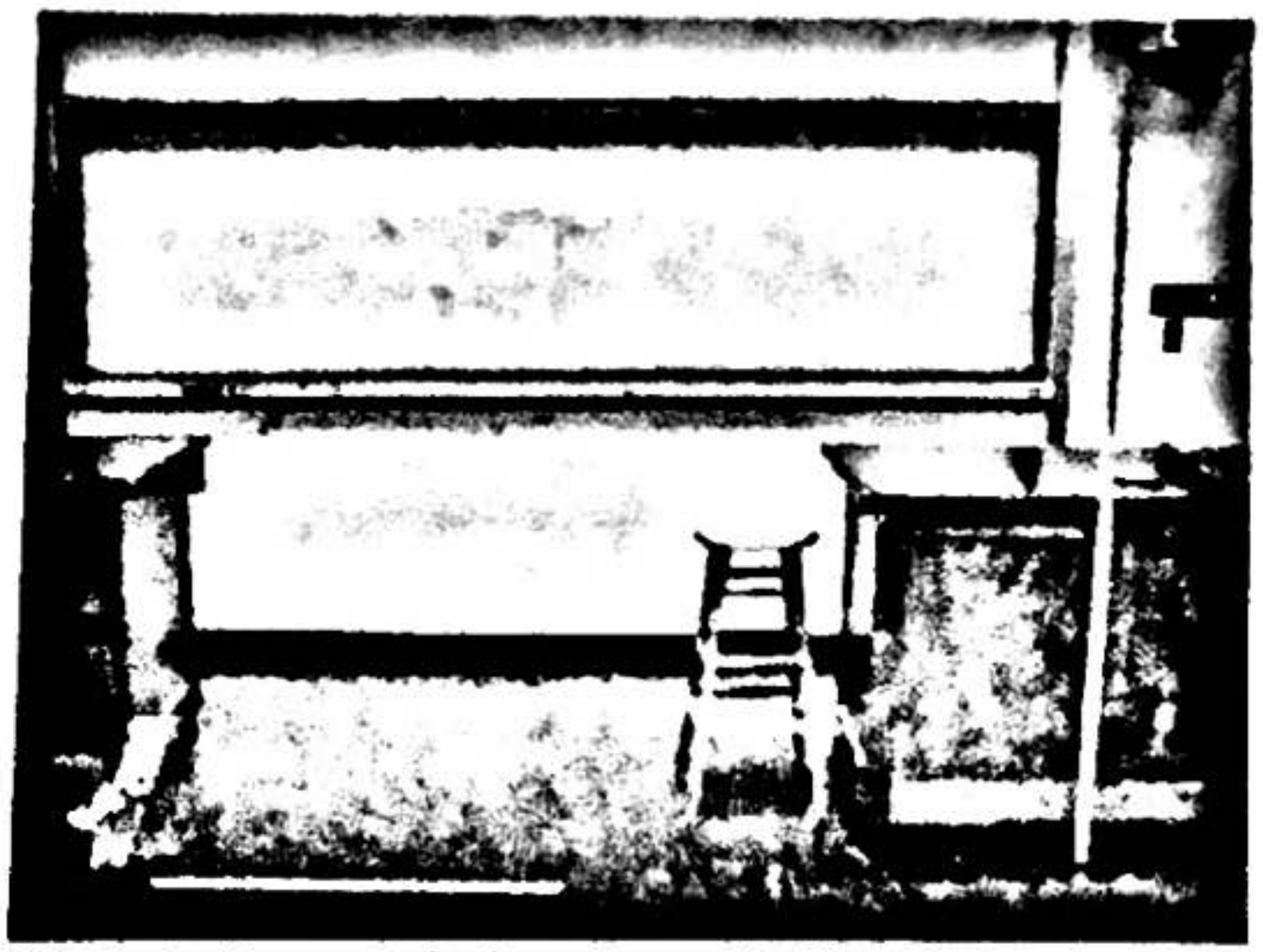


Figure 2- Time of flight to vertical (2 meter) stick = 0.40 seconds

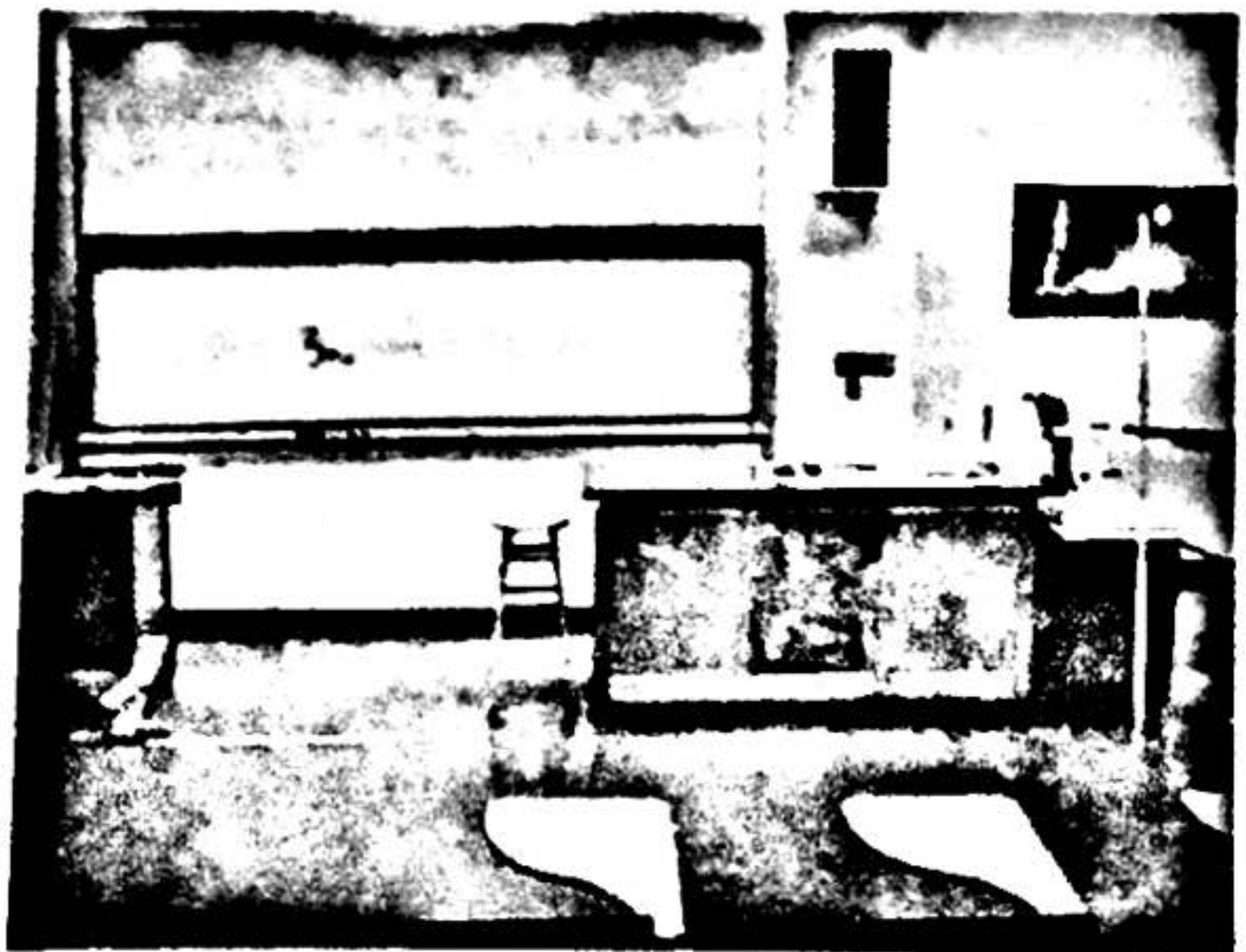
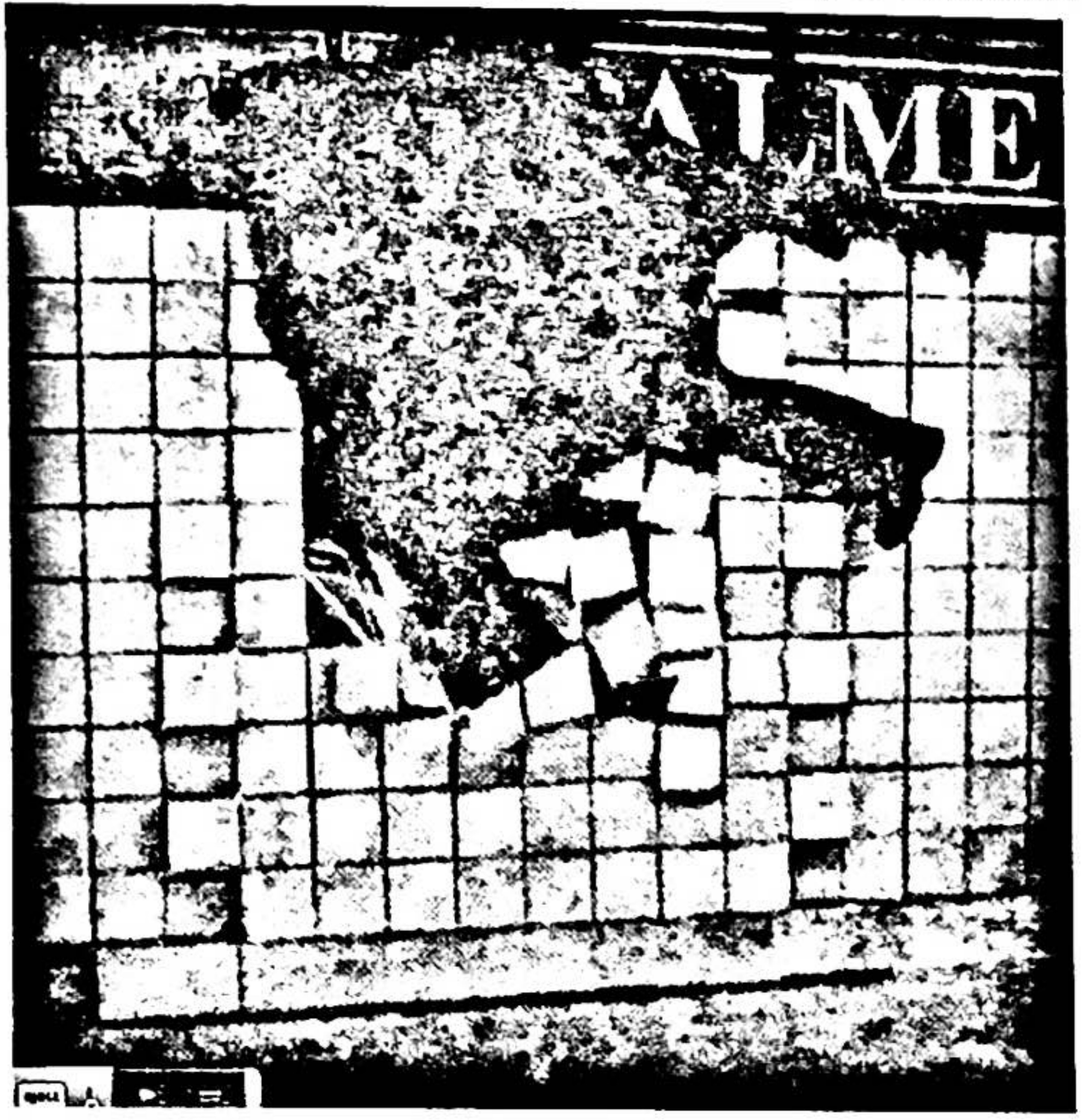


Figure 3- Time of flight to vertical (2 meter) stick = 0.70 seconds

Movie Stills from the Hellboy

(Assume Hellboy is 2 meters tall)



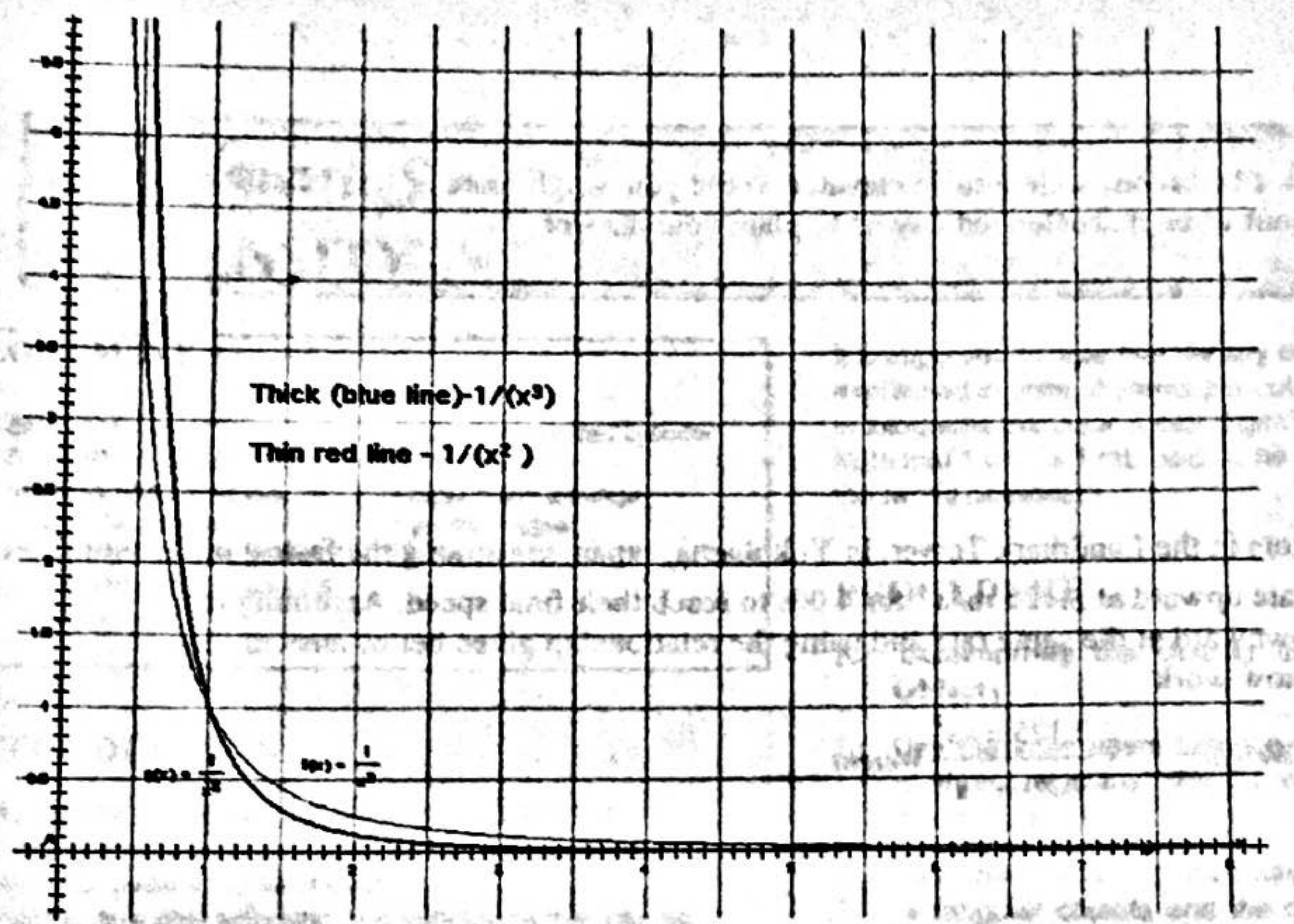


Figure 5- Plot of $y=\frac{1}{x^2}$ and $y=\frac{1}{x^3}$

FIGURE 10.8
With no gravity, the projectile would follow a straight-line path (dashed line). But, because of gravity, the projectile falls beneath this line the same vertical distance it would fall if it were released from rest. Compare the distances fallen with those given in Table 3.3 in Chapter 3. (With $g = 9.8\ \text{m/s}^2$, these distances are more precisely 4.9 m, 19.6 m, and 44.1 m.)

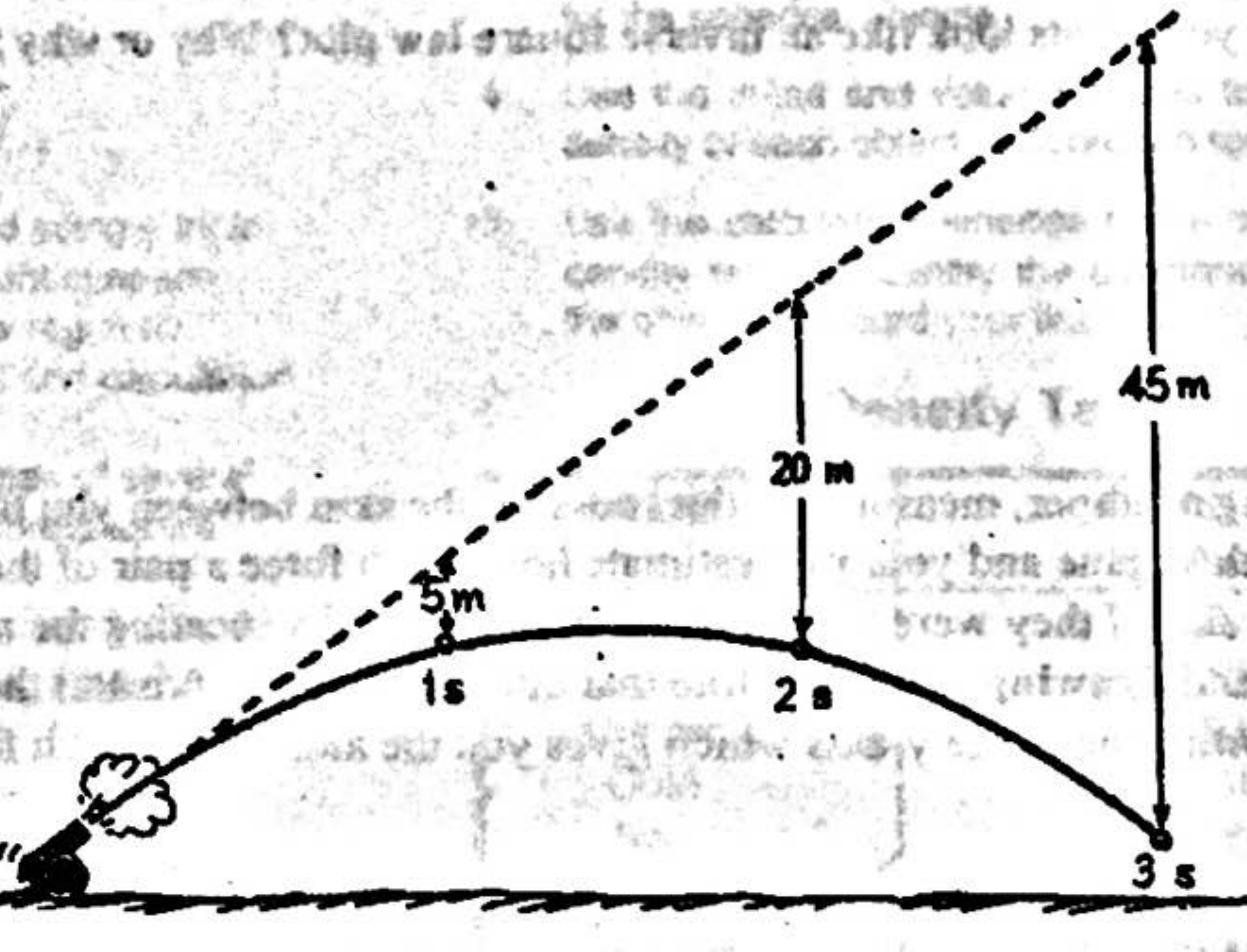


Figure 10.8 from Hewitt textbook

Questions

1. If you took a bathroom scale into an elevator would you weigh more or less when it accelerated up? What about when it accelerated down? Explain your answer.

2. The elevators in the Landmark Tower, in Yokohama, Japan, are among the fastest in the world. They accelerate upward at 3.125 m/s^2 for 4.00s to reach their final speed. Assuming they accelerate downward at the same rate and using the relationship given below answer the following. Show work.

$$Weight_{moving} = Weight_{stationary} \pm \frac{3.125 m/s^2}{9.80 m/s^2} Weight_{stationary}$$

Your maximum weight in elevator = ____________lbs

Your minimum weight in elevator = ____________lbs

3. Did your Plots look like an inverse square law plot? Why or why not.

4. Using a caliper, measure the thickness of the skin between you thumb and index finger Using this value and your plot estimate how much force a pair of the magnets in lab would exert on you skin if they were to pinch you. This is done by locating the measured skin thickness on the x-axis and **drawing a vertical line** that intersects your curve and then extending **(drawing) a horizontal line** to the y-axis which gives you the amount of pinch force.

Pinch force = ______N

5. The sun has a diameter of approximately 870,000 miles. By how much would its gravity at its surface increase it were to shrink down (while maintaining its mass) to *approximately the size of the earth* say to 8700 miles. (Since it's a gaseous body it really does not have a surface). Show work. Remember gravity is an inverse square force law.

Experiment 9
DENSITY

EQUIPMENT

- *1 ERROR Program*
- *1 SPHERE VOLUME program*
- *3 regularly shaped objects of uniform density*
- *2 irregularly shaped objects of uniform density (small & large)*
- *1 100 ml graduated cylinder*
- *1 overflow can*
- *1 triple beam balance*
- *1 vernier caliper*
- *tap water*

INTRODUCTION

The purpose of this experiment is to calculate the densities of various objects and water by finding the mass for a given volume of each.

Density is one characteristic of a substance that can be used to distinguish it from another substance. Density is a measure of the compactness of matter. It is determined by the masses and spacing of the atoms in a substance. More precisely, it is the amount of matter per unit volume. The formula for density is:

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

The mass of an object can be measured using a triple beam balance. The volume is the amount of space occupied by the object. If the object is a regularly shaped solid, appropriate measurement and calculation can determine its volume.

In Experiment 1 we calculated the volumes of several regularly shaped objects. Some of the formulas we used were: for a rectangular solid,

$$\text{Volume} = \text{Length} \times \text{Width} \times \text{Height}$$

and for a sphere,

$$V = \frac{4}{3}\pi \times \left(\frac{D}{2}\right)^3.$$

Sometimes, however, the object whose volume we wish to find is irregularly shaped. To find the volume of such an object, the object is completely immersed in water and the volume of the water it displaces is equal to its volume. This procedure is called the *water displacement* method.

To find the density of a known volume of a liquid, the mass of the liquid can be measured and the density can then be calculated.

It is important to note that density is commonly expressed in units of grams per cubic centimeter (g/cm^3) or kilograms per cubic meter (kg/m^3).

Note that 1 cm^3 = 1 mL, and so no conversion between the two is necessary.

PROCEDURE

A. Determining the Density of Regularly Shaped Objects

1. Use the triple beam balance to measure the mass of three regularly shaped objects. Record the results in grams.
2. Use the caliper to measure the dimensions of rectangular objects and the diameters of spherical objects. Record these measurements in centimeters.
3. Use the measurements made in Step 2 and the computer to calculate the volumes of the objects in cm^3. You may use the SPHERE VOLUME program for the spherical objects.
4. Use the mass and volume values to calculate the density of each object. Record the results.
5. Use the calculated densities of the objects and the density table to identify the substances composing the objects. Record your findings.

Density Table

SOLID	DENSITY (gm/cm^3)
Aluminum	2.70
Brass	8.55
Copper	8.93
Gold	19.30
Iron	7.90
Lead	11.30
Tungsten	19.30
Pine Wood	0.40
LIQUID	**DENSITY (gm/cm^3)**
Alcohol	0.79
Mercury	13.60
Water	1.00

B. Determining the Density of Irregularly Shaped Objects

6. Measure and record the masses of two irregularly shaped objects. Measure the mass of a dry graduated cylinder. Record the value.
7. Determine the volume of each object using water displacement. Two methods are described below:

Method 1 (Small Objects)

- Fill a graduated cylinder with water (about 3/4 full). Read and record the volume of the water.
- Gently drop the object in the cylinder and record the new volume.
- Record the volume of water displaced as the volume of the object.

Method II (Large Objects)

- Place a cup beneath the spout of an overflow can.
- Fill the overflow can with water until the water begins to go through the spout.
- When the water stops coming out, remove the cup and place the graduated cylinder beneath the spout.
- Gently lower the object into the overflow can.
- When the water stops coming out of the spout, record the volume of the water in the graduated cylinder as the volume of the object.

C. Comparison of Volume-Finding Methods

8. Use the water displacement method to once again find the volume of one of the regularly shaped objects from part A.
9. Find the difference between this volume measurement and the one you made in part A.

D. Determining the Density of Water

10. Use the mass you found earlier of the dry graduated cylinder; re-record this on your data sheet.
11. Pour some water into the cylinder and record the volume of this water.
12. Measure and record the combined mass of the cylinder and water.
13. Find the difference between the combined mass and that of the dry cylinder. Record this difference as the mass of the water.
14. Use the mass and volume values to determine the density of the water.
15. Pour out the water from the graduated cylinder. Repeat steps 11-14 once more.
16. Determine the average value of the two trials. Record this value.
17. Find the percent error between your average value of the density of water (measured value) and the value given in the Density Table (true value).

Experiment 9
DATA SHEET

Name: ____________________

Section: ____________________

A. Determining the Density of Regularly Shaped Objects

Shape of Object	Mass of Object (g)	Dimensions of Object (cm)	Calculated Volume of Object (cm^3)	Calculated Density of Object (g/cm^3)	Substance
Sphere		Diameter =			
Silver prism*		______x______x______			
Gold prism*		______x______x______			

***note: silver and gold refers to the colors, not the substances!**

B. Determining the Density of Irregularly Shaped Objects

Mass of Dry Graduated Cylinder:____________g

Object Description	Mass of Object (g)	Volume of Water in Cylinder (cm^3)	Volume of Water in Cylinder with Object (cm^3)	Volume of Object (cm^3)	Calculated Density of Object (g/cm^3)
Small					
Large		▨	▨		

C. Comparison of Volume-Finding methods volume from Part C

Shape of Object	Volume From Part A	Volume From Water Displacement	Difference in Volumes

D. Determining the Density of Water

Trial	Mass of Dry Graduated Cylinder (g)	Mass of Cylinder and Water (g)	Mass of Water (g)	Volume of Water (cm^3)	Calculated Density of Water (g/cm^3)
1					
2					

Average density of water ____________

Percent Error of calculated density of water ________________

QUESTIONS

1. Compare the two methods used in parts A and C to find the volume of a regularly shaped object. Which method do you believe was more accurate? Why?

2. What are the most probable causes for error in your calculation of the density of water?

3. If you were given a hollow metal sphere, could you calculate the density of the metal by using the methods in this experiment? Why or why not?

4. How could you determine the density of your body?

5. What is the density of gold? One ounce of water has a volume of 28.3ml. What is the volume of one ounce of gold in ml?

Experiment 10

WAVES

EQUIPMENT

2 long springs (slinky and coiled spring)
Meter stick
WAVE program
Stopwatch

INTRODUCTION

The purpose of this experiment is to investigate the properties of two types of waves, the superposition of waves, and the principle of standing waves.

Longitudinal and Transverse Waves

These are two general types of waves *transverse* and *longitudinal*. Waves on a string are an example of transverse waves. Light and radio waves are also examples of transverse waves. Sound waves, on the other hand, are an example of longitudinal waves. Consider sound waves traveling through the air. The sound waves consist of areas of compression, where the air density is greater, and rarefaction, where the air density is reduced. It is not the air itself but rather a pulse of energy moving through the air that produces sound waves. Of course, sound waves can be heard and felt, but not seen.

Wave Superposition

When two or more waves meet, they add together to produce a different waveform. Complex waves, those that are not of a pure tone or single frequency, are made from the *superposition*, or addition, of several other waves. Your voice, waves on a string, and some electrical waves are examples of complex waves. You will use a computer program to observe how complex waves are produced. The WAVE program allows you to choose the characteristics of two waves which are to be superimposed. The computer then shows the two original waveforms and the result of their addition.

Standing Waves

Standing waves are a special example of wave interference. If two sets of waves having equal amplitude and wavelength pass through one another in opposite directions, the waves produce areas of constructive and destructive interference that can be observed as positions of maximum and minimum vibration. These positions are referred to as antinodes and nodes respectively.

By vibrating a length of string that is fixed at one end, a train of transverse waves will be sent down the string and then reflected back. If the tension in the string is adjusted, standing waves can be set up in the string. The number of standing waves produced is determined not only by the tension in the string but also the mass per unit length of the string and the vibrating frequency. This demonstration will use a driver to produce an incident wave train along a string fixed at one end. Tension in the fixed end is produced by suspended masses. By varying the tension, different numbers of standing waves can be produced.

The laboratory instructor will demonstrate this type of standing waves using the driven string system at the front of the lab.

As noted above, standing waves are characterized by *nodes* and *antinodes*. In the case of the vibrating string, nodes are points on the string where no vibration is apparent. At these points there is no displacement of the string. Antinodes are points of maximum vibration and displacement of the string.

PROCEDURE

A. Longitudinal and Transverse Waves

1. Attach a piece of tape to a single coil of a spring, about one or two feet from the end, and stretch the spring along a smooth floor with you at one end and your partner at the other.
2. While your partner holds one end still, reach a short distance down the spring's length and gather the coils toward you. Quickly release the gathered coils. Repeat this several times and then let your partner try it. Notice the direction in which the pulse travels and the direction in which the coils of the spring move. Pay special attention to how the piece of tape behaves as the longitudinal pulse goes through the spring.
3. Continue producing longitudinal pulses and observe the speed of the pulse as it travels down the length of the spring. Vary the speed of the pulse by changing the tension in the spring.
4. While your partner holds one end of the spring still, "pluck" the spring sideways. Do this until

you are able to send a pulse shaped like a hump down the length of the spring. Observe the motion of the coils and the piece of tape as the pulse travel through the spring. Observe the speed of the transverse pulse. Vary the speed of the pulse by changing the tension in the spring.

5. Pluck the spring as in Step 4, but pay special attention to how the pulse behaves when it reaches the end of the spring held stationary by your partner. (Notice whether the pulse inverts or remains the same).

Q1: See data sheet to answer question 1 now.

6. Pluck your end of the spring at the same time as your partner. Try plucking from the same side and from opposite sides. Observe what happens when the pulses meet along the spring.

Q2. See data sheet to answer question 2 now.

7. Using the tightly coiled spring, stand three or four meters apart and hold the spring so it doesn't sag much. While one partner uses the stopwatch to time, strike the spring with a ruler and watch the pulse reflect back and forth. Measure the time for the pulse to make 3 round trips. (Six trips down the spring.) Measure the distance between you and your partner with the meter stick. Double this and record your round trip distance. Divide your calculated round trip distance by 3 to determine the time for one round trip. Determine the speed of the wave on the spring by dividing your round trip distance by this time.

Q3. See data sheet to answer question 3 now.

You have observed that the speed of a wave depends on the medium (the spring with different tension is another medium).

B. Wave Computer Simulation

The application **YP Waves** allows you to simulate and view the motion of single waves and then to add two or three waves together and view the result of wave addition or superposition.

8. Open the folder entitled **exp__11_waves**. Double click on the program **YP Waves** to open it. On the taskbar, select **Waves**, and choose *1 Wave*. Under **Animation** on the taskbar, choose **Change Characteristics**. Select the button for Wave 1 and make the amplitude 50m, the wavelength 80 m, the phase 0 degrees, and the velocity –320 m/s.

9. Under **Animation** choose **show wave 1** and observe the characteristics of the wave; then start the animation (under **Animation → Start Animation**, or the apple key + G) and observe wave 1 in motion. Which direction is it traveling?

10. In the Characteristics Window, explore the 4 characteristics that you can change (amplitude, wavelength, velocity, and phase). Make a change to one characteristic at a time, and click the button that says: *Apply These Characteristics* to see what affect that change has on the frequency and on the graph. When you're done exploring and answering questions, return the amplitude to 50m, the wavelength to 80 m, the phase to 0 degrees and the velocity to –320 m/s.

Q4: See data sheet to answer question 4 now.

11. On the taskbar, select **Waves**, and choose *2 waves*. In the Characteristics Window, select wave 2 and give it these values: amplitude 50m, wavelength 80m, phase 0, and velocity 320m/s.

12. Under **Animation,** choose **Hide Wave 1; Show Wave 2; Start Animation** and observe the motion of Wave 2 when animated. Which direction is it traveling?

Q5 & Q6: See data sheet to answer questions 5 and 6 now.

13. **SUPERPOSITION –Under Animation, select Show Wave 1, Show Wave 2, and Start Animation** and observe the two waves traveling in opposite directions past each other. Now let the computer add the two waves together. **Select Animation→Show Resultant Wave.**

Stop the animation when the peaks of the two waves coincide and draw a graph of the resultant wave (Q7 a. on data sheet). Then stop the animation when the two waves pass peak to valley and draw the resultant wave. (Q7 b. on data sheet). (Note: use apple key + G to stop and restart the animation.)

14. ADDITION of THREE WAVES – On the taskbar, select **Waves**, and choose 3 *waves*.

You will now add three waves; set each to the same amplitude and traveling with the same velocity, but with frequencies of 4, 8, and 12 Hz. (You may use the calculator to find the required wavelengths. You will use the following formula, with 320 m/s for your velocity, and substituting the desired frequency to find the appropriate wavelength for each.

$$\text{wavelength} = \frac{\text{velocity}}{\text{frequency}}$$

Observe the sum, or resultant, of these three waves and observe the animation of the superposition of these waves.

Q8: See data sheet to answer question 8 now.

Experiment 10
DATA SHEET

Name: ____________________

Section: ____________________

QUESTIONS:

PART A

1:

a) Describe the motion of the tape as longitudinal pulses traveled through the spring. Compare its motion to that of the direction of the pulse along the spring. What happened to the pulse when it reached the stationary end of the spring?

b) Describe the motion of the tape as transverse pulses traveled through the spring. Compare its motion to that of the direction of the pulse along the spring. What happened to the pulse when it reached the stationary end of the spring?

2: How did the two pulses produced at opposite ends behave when they met along the spring? Elaborate on the fact that there are two possible conditions. Illustrate this with a diagram for each.

3: How did you vary the speed of the pulses in the spring? ____________________

____

Table for Part A. # 7

Distance measured between partners	Round Trip Distance	Time for 3 round trips	Time for 1 round trip (previous time/3)	Velocity of Wave (m/s)

PART B

4:

Which two characteristics affect the frequency? For each, answer if it is directly or inversely proportional to frequency.

__________ directly proportional or inversely proportional
__________ directly proportional or inversely proportional

What affect does changing each of these have on the graph?
Amplitude: ____________________
Wavelength: ____________________
Phase: ____________________

5: When the velocity is negative, which direction does the wave travel? ___________
When the velocity is positive, which direction does the wave travel?___________

6: If the wavelength of a wave is 80 m and it is moving at 320 m/s, what is its frequency?___________.
Show work.

7: a. Draw a graph of the 2 waves and their resultant wave when the peaks of the 2 waves coincide.

b. Draw a graph of the 2 waves and their resultant wave when the 2 waves pass peak to valley.

8: What happens when two waves differing only in amplitude are superposed? Illustrate this with a diagram.

9: What happens when two waves with equal frequencies and amplitudes and a phase angle difference of 180° are superimposed? Illustrate this with a diagram.

10: Explain how you can change the pitch of a string on a guitar. What property of the spring do you vary? Does this change the wavelength of the wave on the string? If so, how? (larger or smaller?)

Experiment 11

HEAT TRANSFER

EQUIPMENT

Thermistor	*Water*
Hot Plate	*Styrofoam cup*
Thermo Program	*Aluminum cup (of comparable size to Styrofoam cup)*
Kettle	
ipod™ Fan	

CAUTION: Handle hot water and hot equipment with care throughout the experiment. DO NOT TOUCH THE ALUMINUM CUP ONCE HOT WATER HAS BEEN PLACED INSIDE!

The purpose of this experiment is to investigate the nature of heating and cooling.

Heat Transfer

Heat transfer between two objects always occurs from the object of higher temperature to the object of lower temperature. The mechanisms for heat transfer are **conduction, convection**, and **radiation**. See next page for definitions of these terms. They will likely be on the lab quiz. The effectiveness of heat transfer depends on how well the medium between the two objects conducts heat.

In this lab you will be using the computer and some temperature probes called thermistors to observe temperature changes. Cooling curves will be constructed so that you can compare how different conditions affect heat transfer and how temperature and boiling are related. A cooling curve is simply a graph of temperature versus time. The slope (steepness) of the line fitting the data is an indication of how quickly the temperature changes. You will investigate how conduction and convection affect the rate of heat transfer. You will also observe that boiling is a cooling process.

PROCEDURE

A. Water Boiling Demonstration

Boiling is a cooling process characterized by the formation of vapor bubbles within the liquid phase as a substance changes from a liquid to a gas. Your instructor will give a demonstration of the temperature curve as water is heated.

B. Cooling by Natural Convection

1. Open the Thermo program in the Physical Science folder.
2. Your instructor will pour boiling water into your Styrofoam cup. Note the time on the wall clock when he removes it from the hot plate. Stir the water with the thermistor. When 30-seconds has elapsed from when the water was removed from the hot plate, press collect in the Thermo program. The computer will take temperature readings for 10-minutes.
3. After the readings are completed, go to *File→Printing Options* and change the title of the graph to Temperature vs. Time (Convection) followed by the names of the people at your table.

C. Cooling by Forced Convection

4. Repeat Part B, but now fan the water with the ipod fan as it cools.
5. Print the graph as before, but instead of "Convection" put "Forced Convection".

D. Cooling by Conduction

6. Repeat Part B, but this time your instructor will pour boiling water into your aluminum cup. Do not fan the aluminum cup as it cools, and DO NOT TOUCH THE ALUMINUM CUP!

7. Print the graph as before, but instead of "Forced Convection" put "Conduction".

TERMS

Heat — Molecular energy that is transferred from one thing to another because of a temperature difference.

Conduction — The transfer of heat energy from an object of higher temperature to one of lower temperature by means of physical contact.

Convection — Heat transfer by the actual motion of a gas or liquid.

Radiation — Electromagnetic waves emitted by all objects at any temperature.

Phase Change — Changing from one form of matter (liquid, solid, or gas), into another.

Experiment **11**

DATA SHEET

Name: ______________________________ **Section**________-

QUESTIONS

1. In Parts B thru C:
    a) which can cooled fastest?___________

    b) which can heated fastest?___________

    c) We know that black is a good absorber of heat simply from wearing a black T-shirt in the sunshine, or touching a black car in the summertime. What can we now conclude about its ability to give off, or emit, heat? Discuss this, and consider this question: Are good absorbers good emitters?

2. Look at the graphs containing the cooling data. Which method of cooling worked best?

3. Give an everyday example of cooling by conduction, by convection, by forced convection.

4. Why didn't you start collecting data as soon as you put the thermistor in the water?

5. Why did you wait the same amount of time before collecting data when comparing cooling methods?

6. Was the heat loss in part D only by conduction? Explain.

APPENDIX

Appendix A
SCIENTIFIC NOTATION

Before you become familiar with various units and conversion factors, an explanation of scientific notation is in order. This method of expressing numbers is not difficult at all. In fact, it often makes awkward numbers much easier to work with. In scientific notation, a number is expressed as a decimal multiplied by a power of ten.

For example, the number 4,000,000 would be easier to write when written as:

4.0×10^6.

As an example at the other extreme, 0.0000000001 would be expressed as 1×10^{-10}.

The computer cannot write superscripts. If the result of a calculation is expressed in scientific notation, the computer will print 1.23×10^4 as 1.23 E+4. Similarly, 4.56×10^{-5} will be expressed as 4.56 E-5.

To see if you understand, let's write the following in scientific notation:

1) 2,100,000,000 = ____________

2) 0.00012000 = ____________

3) 3,050 = ____________

In this lab, you won't usually need to express numbers in scientific notation. However, sometimes you will be dealing with extremely small numbers and your computer will express these numbers in scientific notation.

Appendix B
UNITS AND CONVERSION FACTORS

Units are very important. For instance, if you said someone's weight was 80, this information would be useless. It is necessary to designate 80 what. One choice would be newtons, another pounds, etc. In any type of measurement you must include units to make the measurement useful. Often, one type of unit is preferred over another due to the magnitudes of the quantities being measured. In this lab you will usually be using metric or international units. However, you will occasionally be asked to convert metric units to British units. Systems of Measurement are discussed in Hewitt, Appendix I. p. 686.

UNITS AND SYMBOLS

METRIC

QUANTITY	UNIT	SYMBOL
length	kilometer	km
	meter	m
	centimeter	cm
	millimeter	mm
mass	kilogram	kg
	gram	g
	milligram	mg
force	Newton	N
volume	liter	l
	milliliter	ml
	cubic meter	m3
time	second	s
temperature	Kelvin	K
	Celsius	°C
energy	joule	J
power	watt	W

BRITISH

QUANTITY	UNIT	SYMBOL
length	mile	mi
	yard	yd
	foot	ft
	inch	in
mass	slug	sl
force	pound	lb
time	second	s
temperature	Fahrenheit	°F

CONVERSION FACTORS

LENGTH

	cm	METER	km	in.	ft	mi
1 centimeter=	1	1×10^{-2}	1×10^{-5}	0.3937	3.281×10^{-2}	6.214×10^{-6}
1 Meter=	100	1	1×10^{-3}	39.37	3.281	6214×10^{-4}
1 kilometer =	1×10^{5}	1×10^{3}	1	3.937×10^{4}	3281	0.6214
1 inch =	2.540	2.54×10^{-2}	2.54×10^{-5}	1	8.333×10^{-2}	1.578×10^{-5}
1 foot =	30.48	0.3048	3.048×10^{-4}	12	1	1.894×10^{-4}
1 mile =	1.61×10^{5}	1610	1.61	6.336×10^{4}	5280	1

VOLUME

	METER ^{3}	cm ^{3}	liter^3	feet ^{3}	in ^{3}
1 CUBIC METER=	1	10	1 x 10	35.31	6.102 x 10
1 cubic centimeter=	10^{-4}	1	1×10^{-3}	3.531×10^{-5}	6.102×10^{-2}
1 liter=	1.0×10^{-3}	1×10^{3}	1	3.531×10^{-2}	61.02
1 cubic foot=	2.832×10^{-2}	2.832×10^{4}	28.32	1	1728
1 cubic inch=	1.639×10^{-5}	16.39	1.639×10^{-2}	5.787×10^{-4}	1

MASS

	gram	KILOGRAM	slug
1 gram=	1	1×10^{-5}	6.85 x 10
1 KILOGRAM=	1×10^{3}	1	6.85×10^{-2}
1 slug=	1.459×10^{4}	14.59	1

FORCE

	dyne	NEWTON	pound
1 dyne=	1	1×10^{-5}	2.248×10^{-6}
1 NEWTON=	1×10^{5}	1	0.2248
1 pound=	4.448×10^{5}	4.448	1

Appendix C
GRAPHING DATA

Whenever you collect a set of data, usually in a table of some fashion, it is useful to then create a graph of that data. A graph gives you a visual representation of the data set. It smoothes out irregularities and provides continuity between the data entries. There are a number of different types of graphs that can be used in a given situation, but the most useful for experimentation such as you will be doing is the X-Y graph, (Figure 1).

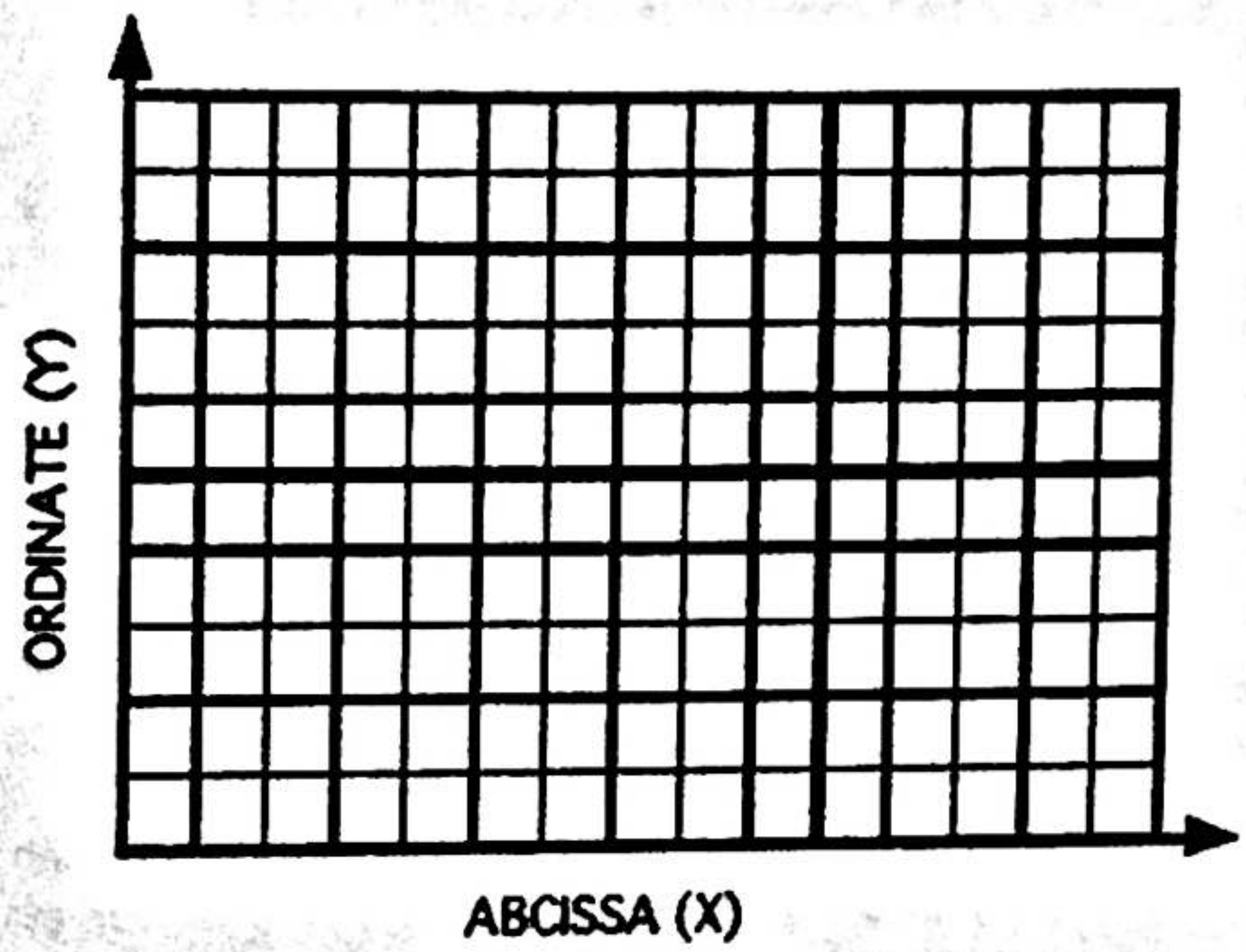


Figure 1

This graph gets its name from the X and Y coordinate axes upon which it is based. Here vertical lines represent the Y-axis and horizontal lines represent the X-axis.

Another name for these axes is ORDINATE (Y) and ABSCISSA (X).

When you do an experiment in lab you are usually trying to determine the relationship between several factors affecting the system under test. In other words, what happens when part of the system is changed. You use instruments to collect the data, but you need graphs to interpret it. Take, for instance, a system undergoing acceleration. You already know, or will soon find out, that the acceleration of an object is equal to the force applied to the object divided by the mass of the object. In formula form this looks like: $a = F/m$. Now suppose you want to test the validity of this formula and to also determine the relationship between acceleration and force. You do this by setting up an experiment where you can change the force applied to the mass, and then measure the acceleration of the mass. You collect the results in a data table such as Table 1.

TABLE 1

Mass 2 kilograms

Trial #	Force applied	acceleration
1	10 Newtons	5 meters/sec.2
2	20N	10 m/s2
3	30N	15 m/s2
4	40N	20 m/s2
5	50N	25 m/s2

The values in the column labeled "Force Applied" represent the different forces used in the experiment. The column labeled "acceleration" shows the result of applying the respective force to the 2-kg mass.

Now, suppose you are interested in what happens at some value of force between those selected for the experiment. A graph can give that information. Here's how.

First you take a piece of graph paper (you will be provided with graph paper) and label the axes, (go ahead and do this as you read about it.) We'll label the Y-axis (vertical) the acceleration axis, and the X-axis (horizontal) the force axis. Look at Figure 2 for a comparison. Note that the labels also include the units associated with acceleration and force.

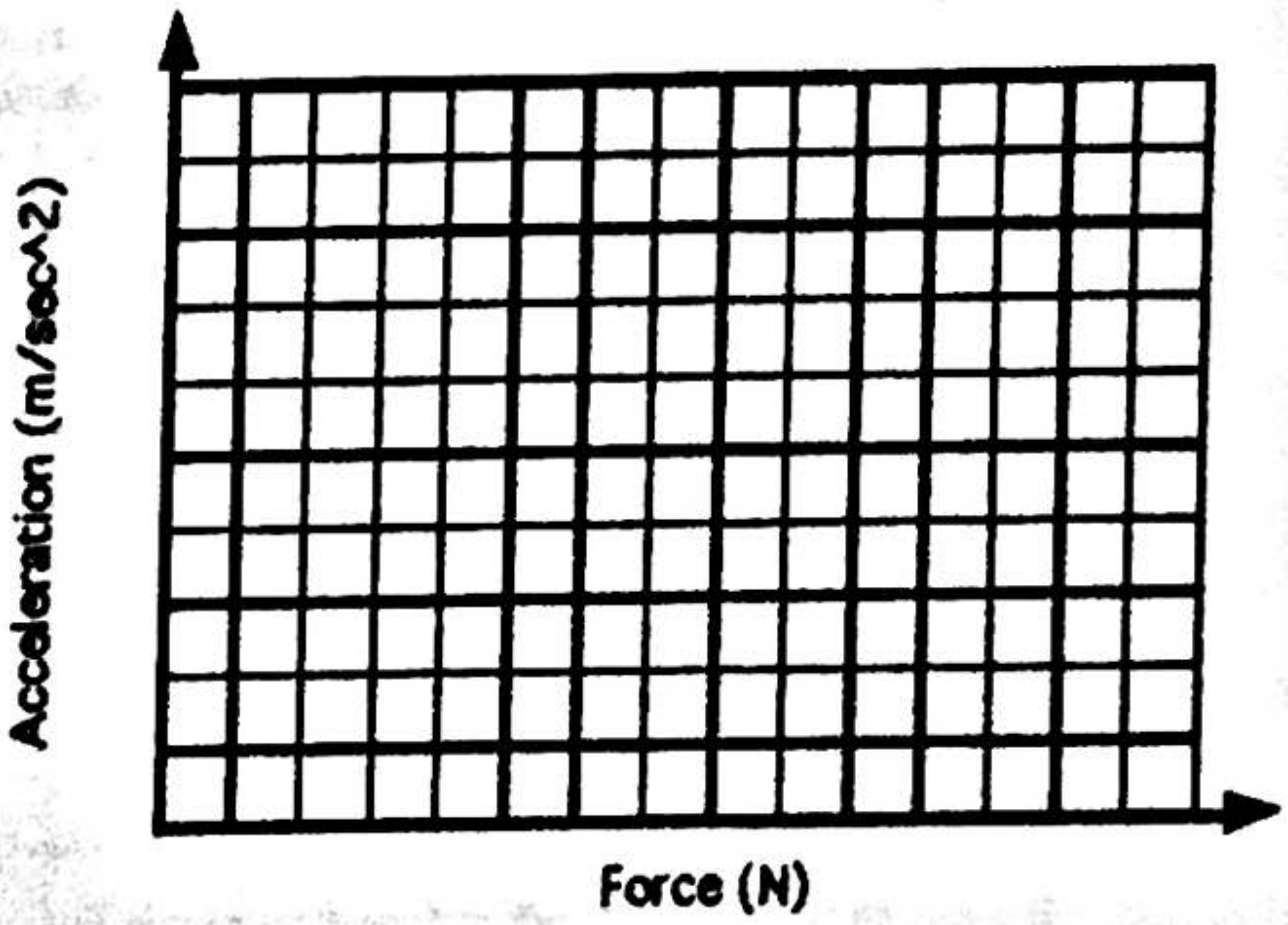


Figure 2

Next you will scale the Y-axis to cover the range of acceleration values from the data chart, and then do the same for the X-axis. Since the acceleration values on the data table range from 5 m/s^2 to 25 m/s^2 it will be convenient to mark our axis from 0 to 50 in increments of 5. The values of force range from 10 N to 50 N so you can mark the axis from 0 to 100 in increments of 10. Check figure 3 to see how this is done.

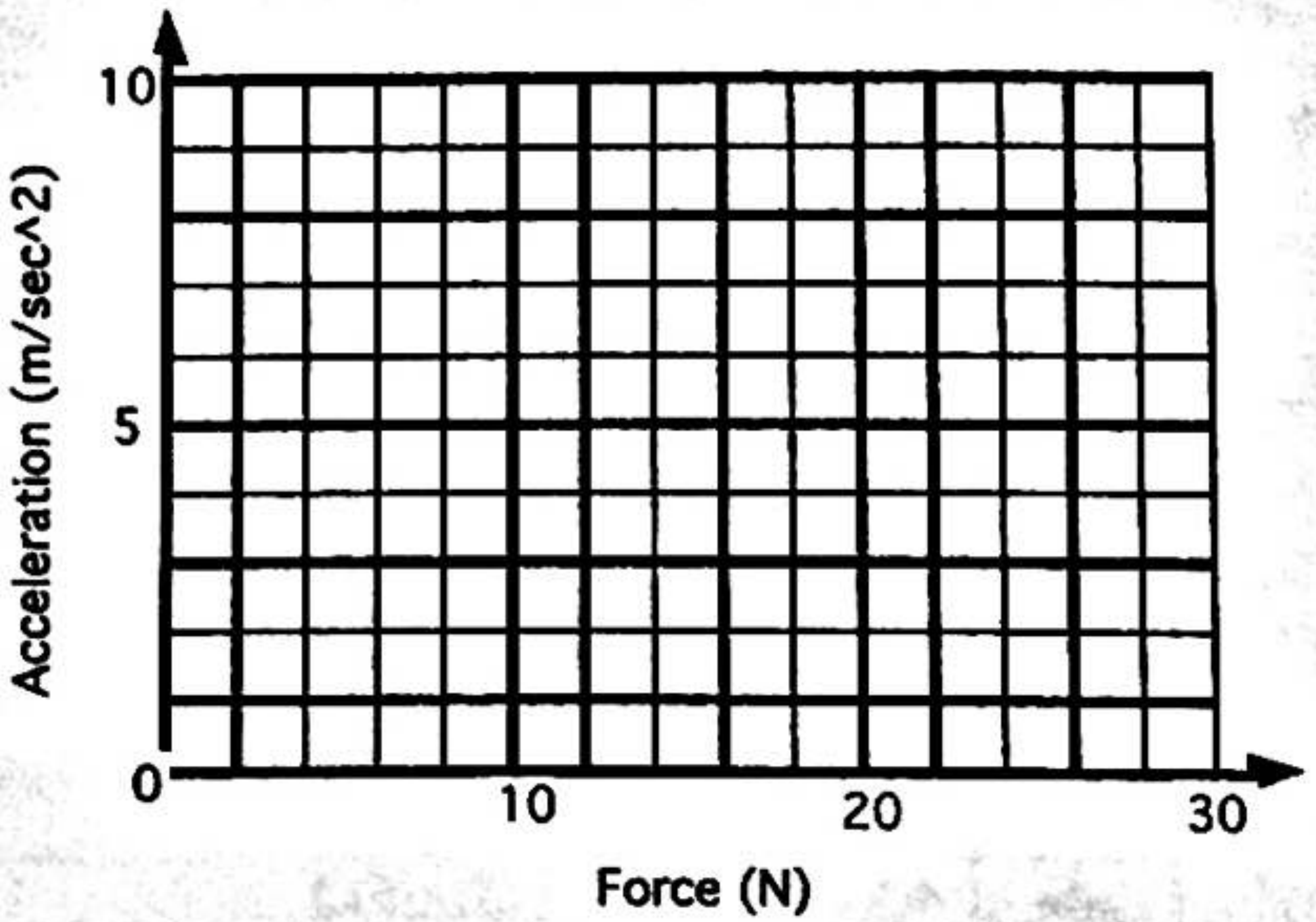


Figure 3

Note that the numbers are assigned to major divisions on the graph paper. Regardless of the actual values of our data you will always try to divide the graph into easily divisible increments (1,2,5,10 etc.) and then plot your actual values on the appropriate division, major or minor.

Now it is time to actually plot your data. Look at trial #1 on the data table. The force value is 10N and the acceleration value is 5m/s2. Find the major division on the abscissa that you marked 10.

Move vertically along this line until you are at the horizontal line marked 5. Now, place a small dot at the intersection of these lines and draw a circle around it. The circle is called a point protector and will help you to find your points after you have drawn a curve through them. Repeat this procedure with each of the other datum sets. You should have dots at the intersection of 20 Newtons and 10 m/s2, and so forth. Figure 4 is an example.

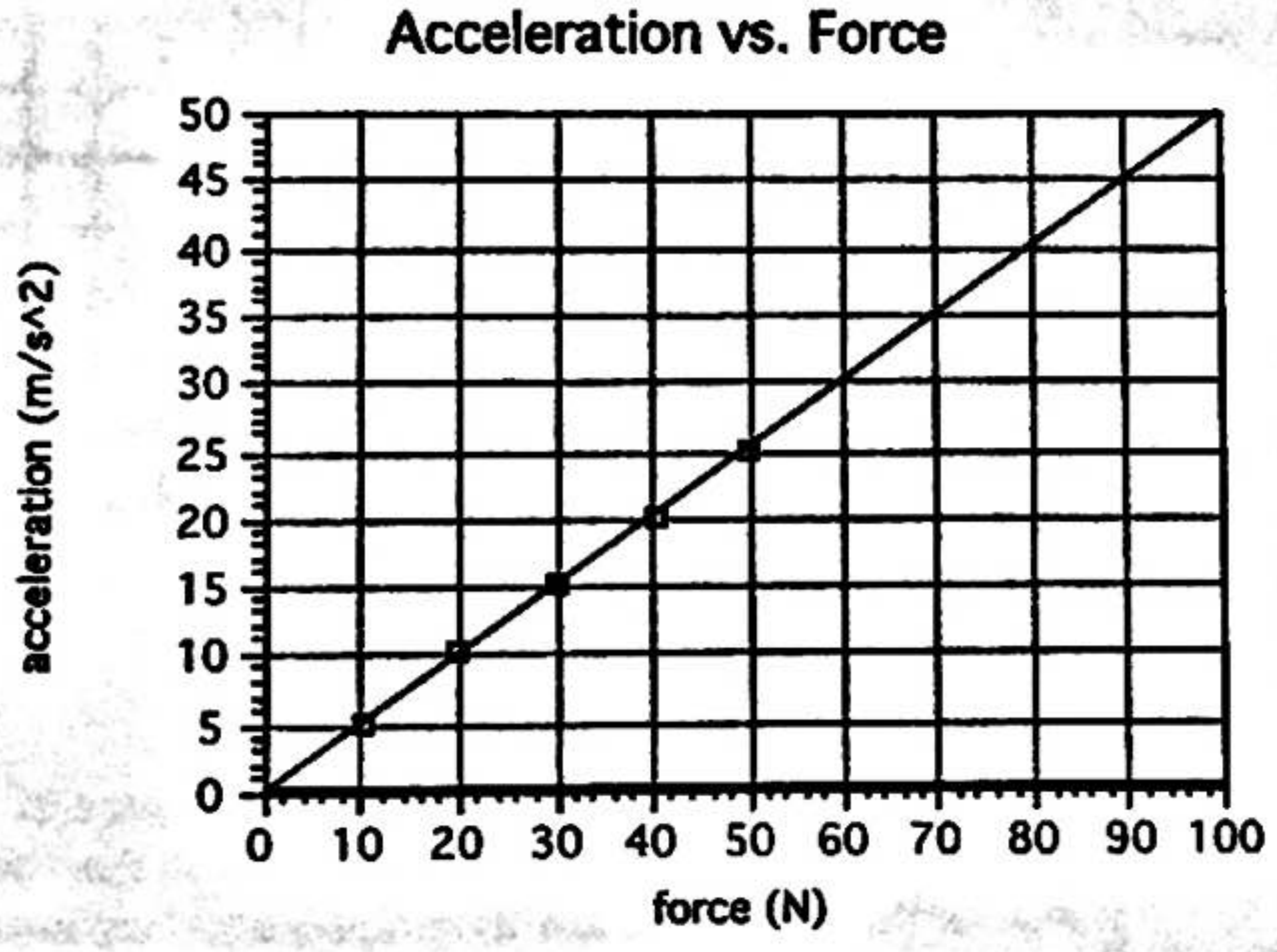


Figure 4

Now you can draw a curve to fit the dots. In this case the curve will be a single straight line, as it will be for most of the graphs that you will make in this lab. It is important to note that it is not necessary for all of the dots to fall exactly on the curve. It is only necessary that you see that the relationship between the variables in our formula is most probably linear. That is, that it looks like a straight-line curve will fit the graph. There are other types of relationships between variables, but these are non-linear(logarithmic, inverse powers, square, etc.), and will generally not be discussed in this lab.

After you have completed your practice graph show it to your lab assistant and discuss any difficulties at that time. If you need additional graphing paper ask for it. Now that your graph is complete, let's take a look at how it can be further utilized to assist in understanding the system under test. Suppose you want to know the acceleration of the system if the force applied is not an even increment of 10N. The curve that you drew on the graph is made up of an infinite number of points; any one of which has corresponding X and Y values. For instance, find the point on the curve that corresponds to a force value of 23N. Yes, that's right, you may have to guess a little bit. That's called interpolation. Now, what value of acceleration corresponds to 23N? Do you come up with a value of 11.5 m/s2? You should be fairly close. Try doing this (interpolation) with some other values. By the way it works the other way, too. If you know the acceleration of the system you can determine the force. This is the beauty of the graph. For practice plot the data set given in Table II on the same graph and axes as before.

TABLE 2

Mass 2 kilograms

Trial #	Force applied	acceleration
1	20 Newtons	5 meters/sec.2
2	40N	10 m/s2
3	60N	17 m/s2
4	75N	20 m/s2
5	90N	25 m/s2

Complete the graph by drawing a straight line which best fits the data. What differences did you observe from the first graph? What might be the cause of the data not fitting a straight line exactly?

In summary, then, let's recall that a graph of our test data provides us with two major aids. First, it helps us to determine the relationship between the variables of a system under test, and second, it enables us to examine this relationship at points other than those that we specifically test.

Appendix D

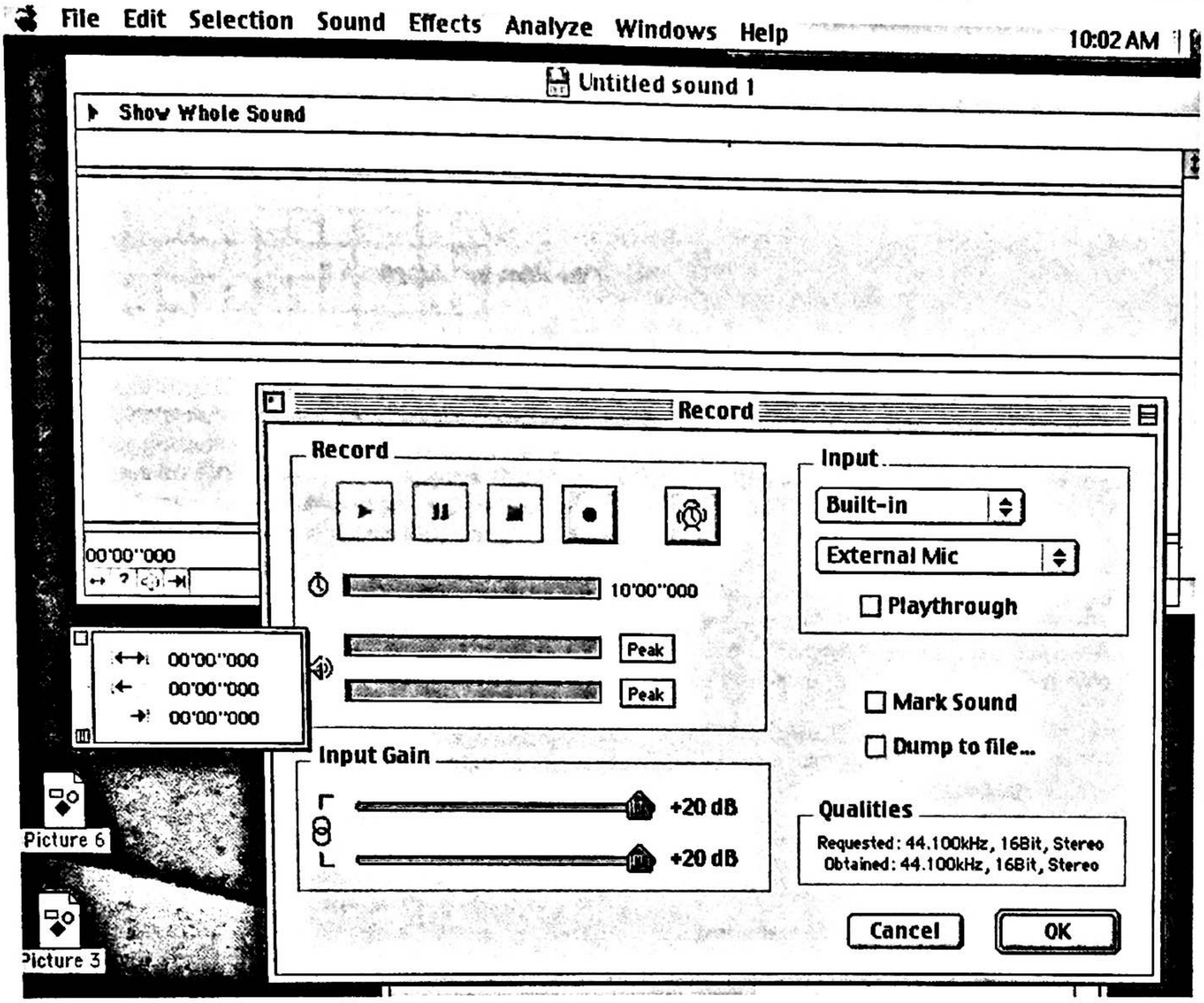
Using the IMac and Amadeus software

Using the iMac and Amadeus II

Amadeus is a sound recording application for use by an iMac. It was originally intended for sound studios and home hobbyists as a means of acquiring sound information for modification and later play back. If an audio signal is connected into the microphone input on the side of the iMac , this signal is sent to an analog to digital converter. That is, it converts analog audio signals (such as a wave vibrating up and down) into digital data that is understood by a computer (a series of ones and zeros). The computer is able to reconvert the digital data back into analog audio data through its associated software application and it is able to store time data associated with every portion of the input sound signal.

In the physics laboratory we can make good use of the recording and storage features of Amadeus to conduct a number of timing experiments. Since Amadeus cannot distinguish between an audio voltage signal from a microphone and other voltage signals, it records any voltage changes fed into the mike input. Therefore, we can input the voltage signal generated by a phototransistor when it goes from an unblocked or high state to a blocked or low state. The corresponding digital pattern shown by the Amadeus program will include the relative times of the change of states of the phototransistor. By correlating these times with the dimensions of the object passing through the gate, we can derive physical information about the motion of the object as it passed through the photogate.

1. Verify that the photogate is plugged into the photogate power supply and that the power supply is plugged into an electrical outlet. Also make certain that there is a cable from the power supply to the microphone input on the side of the computer.
2. Turn the photogate power supply on and rotate the knob fully clockwise to maximize the photogate signal.
3. Turn the computer on and start the program Amadeus II, which can be found in the Apple menu. If no screen appears select --"*New*" from the File Menu. Go to "*Sound*" on the menu bar and select "*Record*" which will open a record window.
5. Slide the input gain to maximum.
6. Press the record button in the record window (the red square button), move your hand through the photogate to block the light signal, and press stop.



Input: Built-in, External Mic

☐ Playthrough

☐ Mark Sound

☐ Dump to file...

Input Gain: +20 dB, +20 dB

Qualities
Requested: 44.100kHz, 16Bit, Stereo
Obtained: 44.100kHz, 16Bit, Stereo

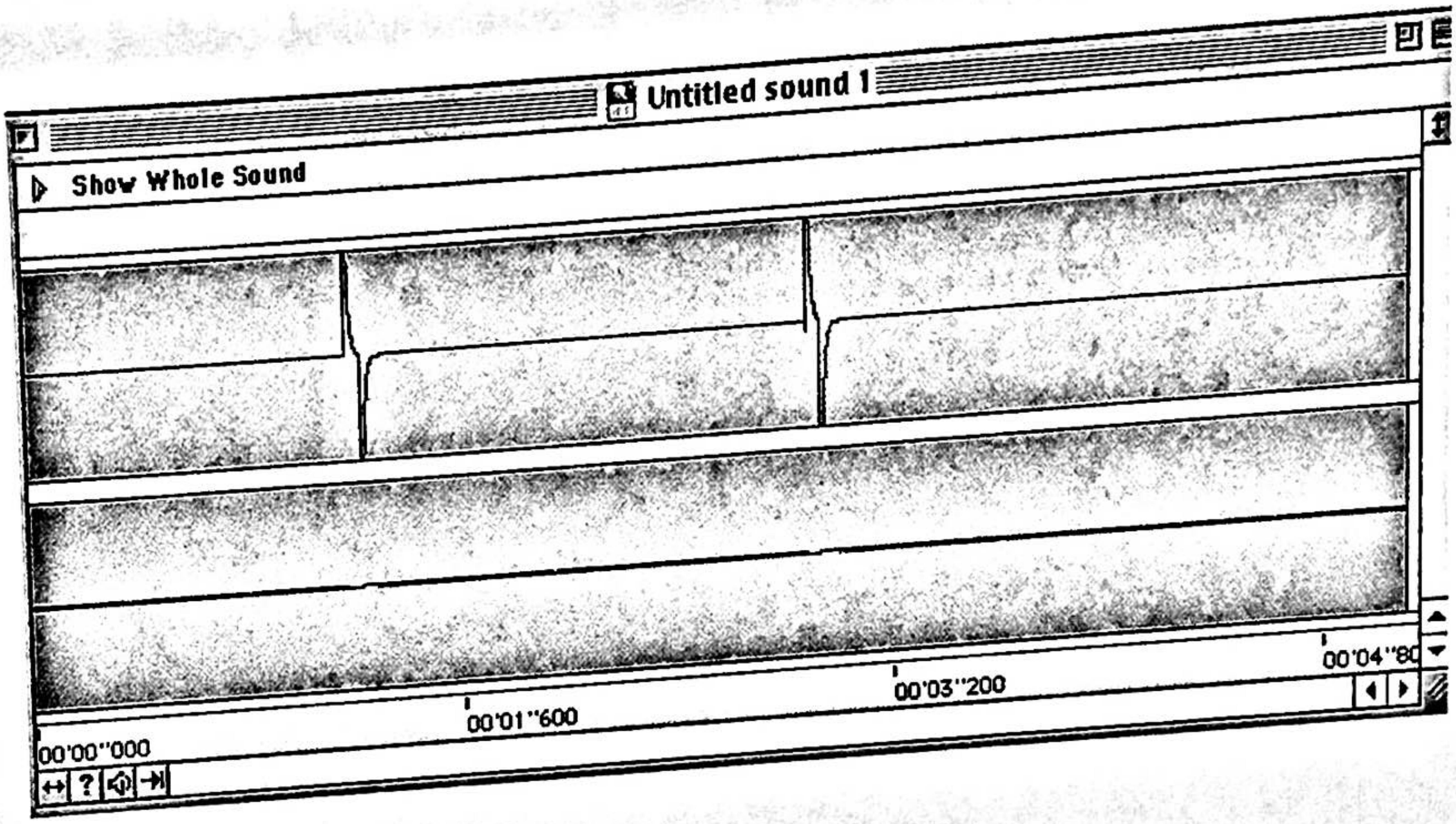
7. Press OK. If everything is connected and working properly, you should see a window with an AC signal of at least two spikes. The positive or upward spike occurs when the light is blocked. The downward spike occurs when the light is unblocked again.
8. Click the cursor on one set of spikes now hit "command g" consecutively until the spikes are spread out so that you can easily distinguish two vertical lines.

9. Click and drag from the first vertical line to the next. You should see a smaller window with three times displayed. The first time is the amount of time your hand took to pass through the photogate beam in milliseconds (1000ths of a second). The second is the time from the collect button section to the time that

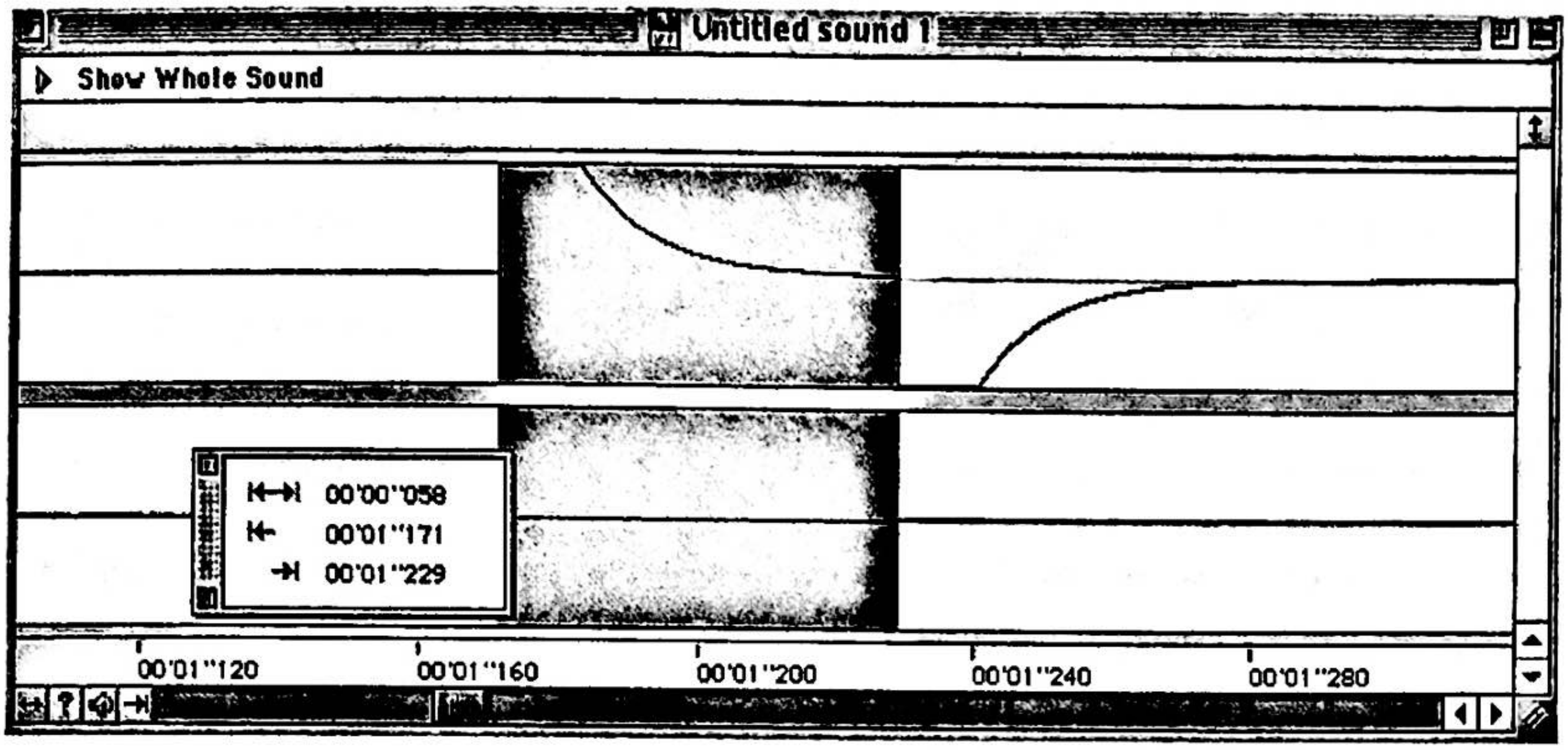
10. the light was blocked. The last time is the time when the light was unblocked. The first time is the time difference between these two time in milliseconds

Determining the Velocity

1. To record a new signal select "NEW" in the file menu. record button.
2. Press record, check that the Input gain is at maximum and press the new
3. Place the car on the track and drive the car around the track passing through the photogate once. Once the car has passed the photogate, click the stop button.
4. Click the ok button and examine your signal.



5. Spread the signal out using the "command g." command.
6. Place a cursor line exactly at the beginning of the leading edge of the first positive peak pulse. This represents the first time that the photogate was blocked during the timed event. Click and drag the cursor from one vertical to the other.
7. Record the time displayed in the cursor time window on a data sheet. It should be much less than one second.



8. Velocity is measured in meters per second, so to calculate the velocity, you must know the exact width of the aluminum bar on the top of the car which blocked the gate when the car passed through the photogate. Use the Vernier caliper to determine the length of the bar. Take note that this width measurement must be converted to meters. The velocity of the car is the measured width of the bar divided by the time determined using the Amadeus program and the computer photogate system. This system of velocity measurement will be used in several laboratory experiments this semester.